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THE DYNAMICS OF NATURAL CLIMATIC CHANGE

John Imbrie, et al

Brown University

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This document contains the results of the effects of ARPA/Brown scientists from 14 August, 1973 to 15 June, 1974. These results include: 1) Organization of a Transfer Function conference sponsored by ARPA and CLIMAP; 2) Identification of methods to improve paleoclimatic estimates derived from transfer functions; 3) Improved coverage of modern pollen data from eastern and central North America; 4) The development of a new uplift model for

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reef terrace sequences; 5) Mapping pollen data at 1000 year time-intervals during the Holocene; 6) Identification of high-deposition rate cores in the Mediterranean and off Cape Hatteras; 7) The discovery that significant phase differences occur in the response times of various parts of the air-sea-ice system during a glacial-interglacial cycle; and 8) The completion of the first experiment to test numerical climatic models against synoptic paleoclimatic data.

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CONTENTS

THE DYNAMICS OF NATURAL CLIMATIC CHANGE:

Semi-Annual Technical Report No. 2 and 3

List of Figures

LIST OF APPENDICES

III Summary of Results

A. General Accomplishments. Progress on several of the specific tasks reported below deserved special emphasis. These include the successful execution of the ARPA-CLIMAP 18,000 YBP climate simulation experiment (discussed as Task 15); the results obtained during the conference on Transfer Functions held at Madison, Wisconsin, April 3-5, 1974 (Task 1); the assembly of pollen maps at selected times during the Holocene (Task 9t); the progress on air-sea interaction studies represented by work on the Gulf Stream off Cape Hatteras (Task 10a) and at higher latitudes (Task 9v); and the development of a new uplift model for reef terrace sequences (Task 8r).

In addition, there are two ARPA-CLIMAP related activities which are time consuming and do not appear on the prescribed list of tasks. First, as a member of the GARP Panel on Climatic Variation, Imbrie made a major contribution to those portions of the report (Gates _et al_., 1974) that deal with paleoclimates. Second, as a member of the US-USSR Joint Committee on Cooperation in the Field of Environmental Protection, Imbrie is scheduled to spend two weeks in the Soviet Union, June 8-21, 1974. He and J. M. Mitchell, Jr. are members of Sub-group 4 of Working Group 8, dealing with evidence from past climates.

B. Specific progress on project tasks. On pages 10-13 of the Brown ARPA proposal dated July 18, 1972, a research plan centered on sixteen numbered tasks was presented. These tasks are listed below. Progress made towards them is discussed in brief progress statements lettered consecutively (a)...... (d'). Those tasks numbered without parentheses will be carried out as ARPA research and will be supported exclusively or predominantly by ARPA funds.

Task 1: TEST ALTERNATE TRANSFER FUNCTION METHODS

(a) A Transfer Function Conference was held at Madison, Wisconsin, April 3-5, 1974, jointly funded by ARPA and by the National Science Foundation's IDOE Program. The organizing committee included Imbrie and Webb of Brown University (who took major scientific responsibility), Kutzbach and Wendland (University of Wisconsin), Fritts (University of Arizona), and McIntyre (Lamont-Doherty). Approximately 30 scientists attended including N. Shackleton and H. J. B. Birks (University of Cambridge) and T. A. Wijmstra (University of Amsterdam). A total of 15 institutions and organizations was represented including: University of Wisconsin, Brown University, Lamont-Doherty Geological Observatory of Columbia University, Oregon State University, University of Arizona, Uni-

versity of Washington, West Georgia College, NOAA, University of Rhode Island, University of Minnesota, U.S. Geological Survey, University of Miami, U.S. Naval Oceanographic Office, Rensselaer Polytechnic Institute, and Yale University. The Conference objectives -- to establish working relationships among workers in the transfer function field; to evaluate the relative merits of competing algebraic methods; to assess the reliability of climatic estimates; and to determine research still needed -- were accomplished. To guide the conference, Imbrie and Webb prepared and distributed a working paper (Appendix A).

(b) A permanent, informal organization of workers in the transfer-function field was agreed to at the Madison Conference. Mr. Douglas Clark of Brown University agreed to distribute a Transfer-Function Newsletter that will serve as a communications net among active workers.

(c) A working group of the Madison Conference headed by John Imbrie dealt with the "No Analog" problem: How can paleoclimatic estimates be validated when the ecosystem structure may have been different from today's? For the marine data a plan was formulated

using the 18,000 YBP samples accumulated as part of the ARPA-CLIMAP modelling experiment. One test involves the simultaneous use of estimates derived from different groups of organisms. A second test involves the use of those core samples in which it is possible to obtain an independent estimate of sea-surface temperature from the isotopic technique of Shackleton and Opdyke (1973). As reported by Shackleton, only in high-deposition rate cores is it possible to obtain reliable paleotemperature estimates using oxygen isotopes. Those estimates are derived by subtracting the values obtained for benthonic fossils from the values obtained for planktonic fossils. High deposition rate cores, however, constitute only about 20 percent of those used in preparing the 18,000 YBP map.

(d) A second working group, headed by T. Webb, dealt with the problems of establishing and applying transfer functions to pollen data on time scales of 0-1000 years and 0-100,000 years. Because transfer functions were first applied to pollen data spanning 10,000 years (Webb and Bryson, 1972), the assumptions and procedures of this initial work must be modified when working with data on other time scales.

ARPA-supported work at the University of Wisconsin (directed by Drs. J. E. Kutzbach and A. Swain) has produced a 0-1000 year pollen record from annually-laminated lakes. With these data, methods must be found to filter out pollen variation from fires, soil differences, and human disturbance, in order for the climatic message to become evident.

Few cores contain a pollen record of 100,000 years or more. The pollen data in these cores are critical in coordinating the land and sea records. Three of these cores are located in the Mediterranean area where human disturbance of the vegetation dates back over thousands of years and where few samples of the modern pollen currently exist. The group agreed that pollen changes in the fossil record are much larger than the changes imposed by human disturbance and that modern samples from the area should be gathered. T. A. Wijmstra, who has worked on some of these cores, agreed to collect and analyze the needed modern samples from initial analyses of the core in Macedonia (Wijmstra, 1969).

(e) A paper prepared by T. Webb and D. Clark was presented to show empirically the differences in estimated climatic values that result from differences in

the numerical techniques used to derive transfer functions. Significant differences appear in the analysis of fossil records, e.g. 3°C versus 6°C changes in temperature. These results emphasize the importance of a thorough examination of the algebraic, statistical, and biological features of each technique in order to identify the optimal technique for a given set of data.

Task 2: DEVELOP OPTIMAL TREND-SURFACE TECHNIQUES

(f) No work has been done since that reported in Semi-Annual Technical Report No. 1 in which we described a contouring program. We have decided that it is not feasable at this time to carry on with the more sophisticated "optimal trend-surface" objective stated in our initial proposal. This objective was to develop formal procedures for drawing contours with limited control points and take into account physical oceanographic theory, instead of using the simple interpolation schemes characteristic of automated contouring programs. Discussion with oceanographers convinced us that research on the problem is not likely to yield results soon.

Task 3: COLLATE MODERN POLLEN DATA FOR EASTERN U.S.

(g) Data on 115 samples of modern pollen were added to the 800 samples compiled in the first year. The new data included samples from northwestern Nebraska, northern Montana, central Florida, and central Ontario. These data were derived from published tables and from unpublished tables made available by Dr. J. H. McAndrews (Royal Ontario Museum, Toronto).

(h) Maps were prepared showing the distribution of each of the major pollen types in central and eastern North America (Figures 1-7). These maps were presented and discussed in two papers at the INQUA meetings in New Zealand in December, 1973 (Appendix B and C). Manuscripts describing this work are now in preparation (Davis and Webb, in prep. and Webb and McAndrews, in prep.). These manuscripts and maps will inform scholars of the locations of modern samples and will illustrate those areas most in need of additional sampling.

(i) As part of the analysis and presentation of patterns in the distribution of pollen data, multivariate statistical techniques are important (see Webb, 1974). These techniques reveal which patterns are most prominent within the data and summarize the im-

portant information. Because several possible techniques can be used, each utilizing different assumptions about the data, work was undertaken to compare the results of three of these methods -- e.g., principal components analysis, canonical variate analysis (closely related to multiple discriminant analysis), and cluster analysis -- on a subset of the large set of modern samples. The result of this work shows that the same basic structure in the data appears no matter what technique is used. Slight differences in the details of each technique, however, are important in revealing different aspects of the data. A manuscript is now in the final stages of preparation describing this work (Birks, _et al_., in prep.).

(j) In cooperative work at the University of Wisconsin, Webb provided advice to Mr. G. Peterson for the compilation of modern pollen samples from the Soviet Union.

(k) Close working ties were established with H. J. B. Birks (Cambridge Univ., England) and J. H. McAndrews (Royal Ontario Museum, Toronto, Canada) for data exchanges and for sharing methods for statistical analysis of data (Birks _et al_., in prep.).

Task 4: IMPROVE ABSOLUTE CHRONOLOGY OF THE 30,000-130,000 YBP INTERVAL

(l) There is no circa 40,000 YBP terrace on Barbados. A terrace approximately two meters above sea level and of limited geographic distribution was previously suspected to be circa 40,000 YBP. Detailed mapping, sampling, and carbon-14 dating now clearly indicate this feature to be less than 4,000 years old, essentially Recent. We are lead to the firm conclusion that any high stand of the sea which occurred in the time range 10,000 to 60,000 BP did not reach high enough to be recorded above sea level on Barbados.

(m) Additional dates are being obtained on the "60,000 YBP" Barbados terrace. The 60,000 YBP interstadial is recorded in temperature estimates from many North Atlantic cores and appears to be the last major warm interval before the onset of full glacial conditions. It is therefore important that we get as accurate an estimate as possible of the timing and elevation of this high stand. Additional Barbados samples are being analyzed and will hopefully accomplish this purpose.

Task 5: EXTRACT POLLEN DATA FROM THE LITERATURE AND INTERPRET IT IN TERMS OF CLIMATIC TIME SERIES

(n) The data obtained from 50 long pollen cores with radiocarbon dates from 0 to 15,000 B.P. have been key punched and stored on punch cards. In addition, data from 20 other long-cores have been added to this data set. All the time-stratigraphic information (mainly radiocarbon-dates) have been recorded and is being used in selecting pollen data at 1,000 year time-intervals during the Holocene for presentation on maps (see Task 9).

Task 6: OBTAIN AND INTERPRET NEW POLLEN DATA

(o) In light of these initial maps, new samples have been collected in central Nebraska through cooperation with Dr. L. V. Benson (Dept. of Geology, Univ. of Nebrasks). These samples provide data from previously unsampled areas. Data from Kentucky, Illinois, and Missouri have also been collected, processed, and added to the data set through cooperation with palynologists at the University of Wisconsin.

Task (7): OBTAIN SEA-SURFACE PALEOTEMPERATURE DATA FROM HIGH-DEPOSITION-RATE MARINE CORES

(p) Work is proceeding on high-deposition rate cores in the Curiaco Trench (off Venezuela). Although we have identified a 180 and 380 year periodicity in the faunal data, reliable paleoclimatic estimates are

not yet possible because of the restricted fauna. We are currently preparing a data set from which we can derive a more reliable transfer function for this unusual fauna.

Additional high deposition rate cores have been identified from the Santa Barbara basin off California. Those cores have varves that can be correlated with varves in dated cores back to about 1100 A.D. Work is in progress on extending these correlations, and analyzing the fauna in these cores.

Task 8: DETERMINATION OF SEA-LEVEL FLUCTUATIONS IN THE RANGE 75,000-130,000 YBP

(q) Progress on this task in general is reported by Matthews (1974) (abstract attached as Appendix D) and Bloom _et al_. (1974) (abstract and key figures attached as Appendix E). Barbados and New Guinea data are compatible to a first approximation and indicate numerous high stands of the sea separated by low stands of considerable magnitude (20 to 70 meter variations in sea level within 5,000 to 10,000 years).

(r) A new uplift model has been developed (Appendix F) that affords a more precise evaluation of tectonic effects on terrace sequences over short intervals of time. RKM is presently collaborating with John Chap-

pell of Australian National University concerning application of the model to New Guinea data. This study should produce more precise estimates of the history of sea-level dynamics.

(s) The 125,000 YBP high stand lasted no longer than 5,000 years, was preceded by a 25 meter sea level rise, and was followed by sea level lowering at a rate of 5 to 10 meters per thousand years. Mangion and Matthews (1974) abstract is attached as Appendix G.

Task 9: OBTAIN NEW CLIMATIC TIME SERIES FOR NORTH AMERICAN POLLEN CORES

(t) Forty-four maps have been produced to show the distribution of major pollen types (spruce, pine, oak, and herbs) at 1000 year intervals during the Holocene. In addition, difference maps have been constructed to show changes in pollen distributions from one time interval to the next. These maps (Fig. 8) show clearly the changes in the pollen (and by inference vegetation and climate) as the ice retreated northward. A manuscript (Bernabo, Webb, and McAndrews, in prep.) is now being prepared to present these maps. This manuscript will illustrate to palynologists where more samples are needed, espe-

cially if synoptic maps of the pollen data are to be constructed. Although mapping the data is critical for paleoclimatological studies, few Quaternary palynologists have attempted to map their data (see McAndrews and Power, 1973; Webb, 1974).

(u) Work continued on finding or writing computer programs for compiling, editing and updating pollen data. Work was begun to tie these file-handling programs in with the programs for finding transfer functions and for plotting or mapping the output.

(v) A project was started with Dr. W. Ruddiman (U.S. Naval Oceanographic Office) to study the teleconnections between climatic patterns over eastern North America and the central North Atlantic. This project combines the paleoclimatic information of pollen data with the paleo-oceanographic data of planktonic foraminifera.

Task 10: OBTAIN NEW CLIMATIC TIME SERIES IN HIGH-DEPOSITION-RATE MARINE CORES

(w) Two high deposition rate cores have been identified off Cape Hatteras, North Carolina. Sedimentation rates between radiocarbon-dated postglacial and late glacial horizons reach 27cm/1000 years; the full glacial sedimentation rate probably exceeded 50cm/1000

years. By examining pollen and foraminifera from identical core samples, oceanographic changes, in particular Gulf Stream migrations, can be directly correlated with changes in terrestrial vegetation. Initial results indicate that there is a slight time lag (500 to 2000 years) between changes on land and sea, with the sea leading the land. A manuscript describing this work is being prepared (Balsam and Florer, in preparation).

(x) We have identified high-deposition-rate cores in the eastern Mediterranean that are amenable to transfer function analysis. Data presented in papers by Todd (1958) and by Parker (1958) have been analyzed in our laboratory by transfer function techniques. The result is an equation which satisfactorily estimates paleotemperatures and salinity in Mediterranean cores. Sufficient C-14 and stratigraphic data are available to prove that at least one core off the Nile delta (Core 184) has a deposition rate of about 40cm/1000 years, and penetrates the entire Holocene. This opportunity will be exploited during the coming year.

Task (11): CORRELATE CLIMATIC RECORD OF THE ICE CORES

(y) A short paper (Andrews *et al*., 1974, in press) represents the application of correlations made by Sancetta *et al*., (1973) between North Atlantic core V23-82 and the Camp Century ice core record. Andrews *et al*., conclude that as suggested by Imbrie (1972) snowfall in the Baffin Island region was lower than normal during the 18,000 YBP maximum-glaciation interval.

Task (12): COOPERATE WITH GLACIAL GEOLOGISTS IN OBTAINING ACCURATE ICE MARGIN POSITIONS FOR SELECTED TIMES DURING THE PAST 130,000 YEARS

(z) A critical element in the ARPA-CLIMAP 18,000 YBP modelling experiment was the availability of accurate data on the margins and elevations of ice-sheets. These data were assembled on a global basis by Dr. George Denton of the University of Maine and Dr. Bjorn Anderson of Norway. This compilation was made expressly for the ARPA-CLIMAP experiment. A conference held at Brown during December, 1973, made the final integration between ice-margin and sea-surface temperature data used for the experiment.

Task (13): IDENTIFY SIGNIFICANT FREQUENCIES IN CLIMATIC TIME SERIES

(a') Research is in progress on long Pacific deep-sea core records, in cooperation with N. Shackleton,

of Cambridge. The initial result was a spectrum for Pacific core V28-238, which showed a significant 100,000-year periodicity and insignificant spectral peaks in the vicinity of 40,000 and 20,000 years (Fig. 2 of Semi-Annual Technical Report No. 1 was reproduced in Appendix A of the Report to the GARP Panel on Climatic Change.) Current work will result in a spectrum from a second long Pacific core (V28-239). If the same frequencies appear, we will publish the results.

Task (14): STUDY REGIONAL VARIATION IN CLIMATIC TIME SERIES

(b') This work has led to one important discovery: that significant phase differences occur in the response times of various parts of the air-sea-ice system during the glacial-interglacial cycle. In particular, many parts of the tropical and subtropical sea-surface achieve their minimum temperatures several thousand years before 18,000 YBP, when both the Northern Hemisphere ice-sheets and the oceanic polar front in the North Atlantic achieve maximum southward extent. This fact, reported by Hays (1974), was interpreted by Imbrie (1974) as contradicting the standard Milankovitch theory of the ice ages. For, if the ice-age is triggered by a

high-latitude snow-line reaction, then the low-latitude ocean should respond in phase with or lag behind the ice-sheets. This line of argument has led Imbrie to a re-casting of the theory of orbital control of climate, stressing low-latitude effects. Work along this line forms a significant part of our plan for research during the next two years.

Task 15: COOPERATE WITH ARPA SCIENTISTS IN THE DESIGN AND EXECUTION OF EXPERIMENTS TO TEST NUMERICAL CLIMATE MODELS AGAINST SYNOPTIC PALEOCLIMATIC DATA

(c') Work on this task has been a major pre-occupation of the Brown-ARPA group during the past year. These efforts came to fruition on April 8, 1974, when an eight-paper session at the Meteorology Section of the AGU Meeting in Washington, D.C., was devoted to a description of the design and execution of the ARPA-CLIMAP August 18,000 YBP simulation experiment. This set of abstracts is reproduced as Appendix H. Gates reported a sea-level pressure pattern calculated for August 18,000 YBP. Preliminary analysis by Gates indicates that an intuitively reasonable result was obtained. Current ARPA-CLIMAP activity is focussed on the use of independent data to check the accuracy of the model. The bulk of this test data represent pollen spectra from around the world, compiled and

analyzed mainly at Brown. Conferences are planned during late June and September in which the testing and evaluation of the RAND climatic model will be carried out.

Task 16: IDENTIFY SYNOPTIC PATTERNS OF THE PAST 20,000 YEARS WHICH ARE ANALOGOUS TO EXTREMES DURING THE PAST 130,000 YEARS

(d') Work on this task will begin when additional maps depicting the past 20,000 years and the past 130,000 years become available. We were premature in proposing to accomplish this task, when we wrote the initial proposal in 1972.

IV. TECHNICAL REPORT SUMMARY

A. Purpose of the research. Climate is always changing. The practical as well as the purely scientific value of understanding the processes which bring about climatic change is self-evident. Only by understanding these processes can we comprehend past and predict future climates. To date this goal has not been achieved. What sort of research is needed? In part, the answer will come from an improved understanding of the mechanisms by which the global air-sea-ice system yield a climate in equilibrium with today's boundary conditions. Significant progress in this direction has been made by several numerical models of climate. But this research cannot solve the puzzle of climatic change by itself. We must, in addition, determine what changes in boundary conditions (if any) force climatic change -- and understand the forcing functions themselves. These objectives can only be achieved by studying the workings of the global climate machine over a time span adequate to record a representative range of conditions in Nature's own laboratory. The purpose of ARPA paleoclimate research at Brown is to document and understand climatic changes on time scales ranging from thousands to hundreds of thousands of years.

B. Methodology. Part of our research effort aims at two basic observational problems in paleoclimatography: 1) obtaining accurate, quantitative, paleoclimatic estimates; and 2) constructing

an absolute time scale. The first problem is approached by evaluating and testing a number of multivariate transfer function methods applied to fossil pollen records (obtained from bogs and lakes), and to fossil plankton (obtained in deep-sea cores). The second problem is approached by radiometric dating of the sea-level record contained in the uplifted Pleistocene coral reefs of Barbados, by radiometric and C^{14} dates on marine and terrestrial cores, and by using oxygen isotope data to correlate between cores.

Other research is directed towards obtaining synoptic maps of past climates that illustrate the geographic patterns of climatic change. Pollen-based maps of terrestrial climates are largely the product of ARPA research. Maps of past marine climates are obtained by ARPA investigators working in cooperation with an NSF-funded CLIMAP project. The interpretation of these data is discussed below (Global Atmospheric Modelling Experiment).

C. Technical Results

1. The ARPA-CLIMAP global atmospheric modelling experiment has been run (Task 15). ARPA and CLIMAP scientists used geological data to establish the boundary conditions for a full glacial period (18,000 YBP). The boundary conditions they specified were: sea-surface temperatures, sea-levels, ice-margins, and surface albedo. This body of data is the largest and most diverse body of paleoclimatic data ever assembled for a single time period.

It will probably be refined and may be used to test second generation numerical climatic models. Results of the experiment will be validated using both pollen data gathered by Brown personnel and marine data not used in running the experiment.

The initial results of this experiment, a sea level atmospheric pressure map for full glacial conditions (18,000 YBP), were presented at the A.G.U. meeting April 8, 1974. Analysis of the results and the validation procedure are still in progress, and it will probably be several months before we understand some of the ramifications of the experiment. However, our results in general are positive, and we are now one step closer to understanding climatic change and predicting future climates.

2. Participants at the transfer function conference made significant progress toward understanding how various mathematical techniques modify results (Task 1). As a result, improved transfer functions should produce more accurate paleoclimatic estimates. Computer programs for establishing the transfer functions will also be more widely shared.

3. The development of a new uplift model for reef terrace sequences will enable us to obtain much more accurate figures on the rate of sea level fluctuations (Task 8).

Data on the magnitude and rate of sea level fluctuations (and its inverse, change in glacial ice volume) are critical for testing theories of climatic change.

4. The geographic range of our pollen data set has been extended and arrangements made for obtaining data from most of the Northern Hemisphere (Tasks 3 and 5). Significant progress has been made filling in gaps in the modern data as described in Task 6. Maps are now available showing the distribution of all the important pollen types in eastern North America (Task 3).

5. Synoptic maps of the past distribution of certain pollen types have been prepared from eastern North America for selected intervals of the Holocene and Late Glacial. These maps contain the first clear picture of how the vegetation in a region responds to a major climatic change and what the rate of this change is. The maps illustrate the distribution of the raw data from which paleoclimatic maps will be produced (Task 9).

6. Initial work has been carried out toward developing a system of computer programs capable of handling, transforming, and mapping the large sets of geographically distributed fossil data used in paleoclimatic reconstruction (Task 9).

Figure 1 Distribution of pollen percentages in sediment samples of modern pollen for *Cyperaceae* (sedge), *Salix* (willow), *Betula* (birch), and *Alnus* (alder) pollen. Percentages are based on a sum of total pollen counted excluding aquatic pollen types. Isopleths are contours of equal pollen percentage.

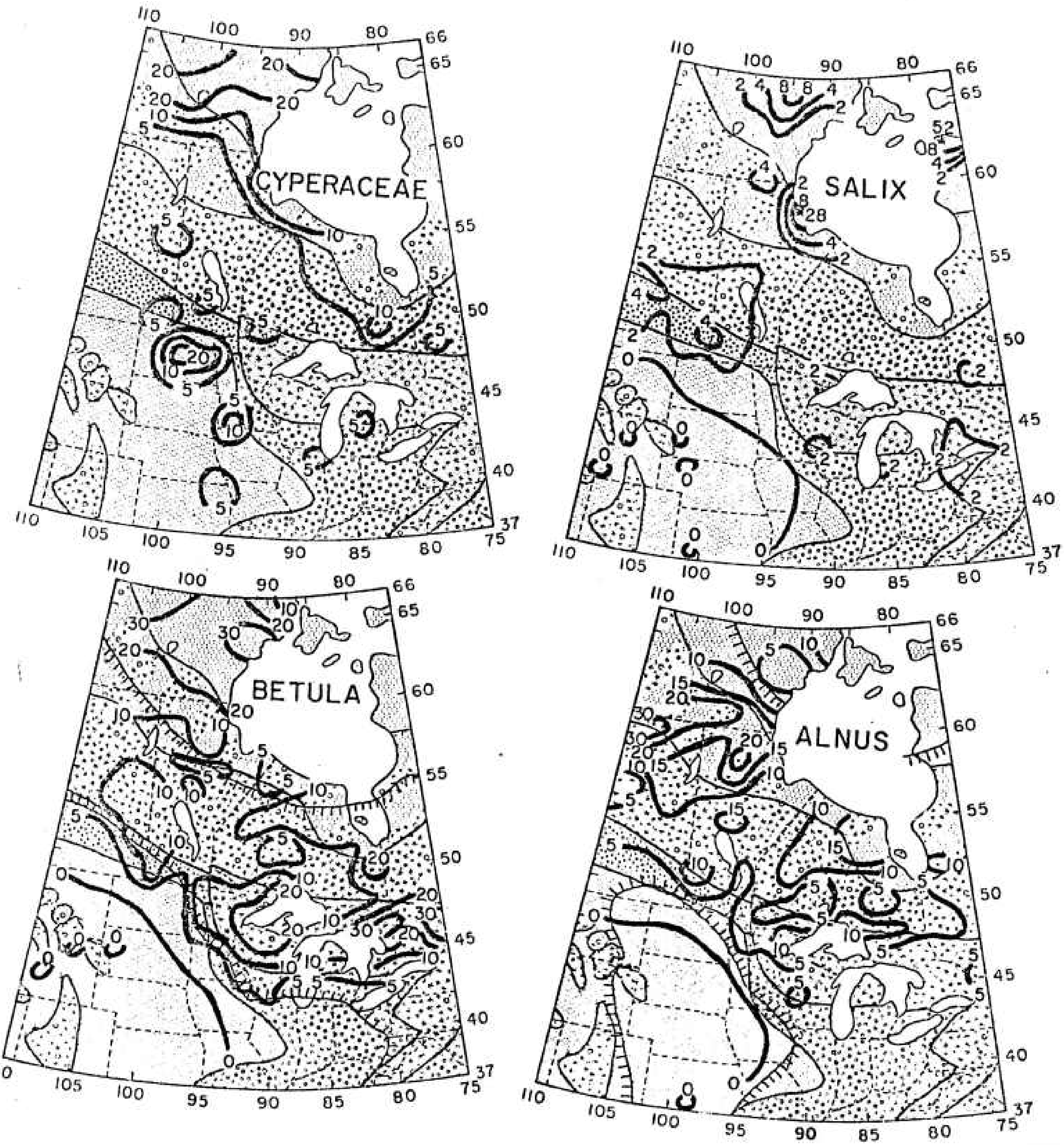

CYPERACEAE
SALIX
BETULA
ALNUS

Figure 2 Distribution of pollen percentages in sediment samples of modern pollen for *Picea* (spruce), *Pinus* (pine), *Abies* (fir), and *Juniperus-Thuja* (juniper-arborvitae) pollen. Percentages are based on a sum of total pollen counted excluding aquatic pollen types. Isopleths are contours of equal pollen percentage.

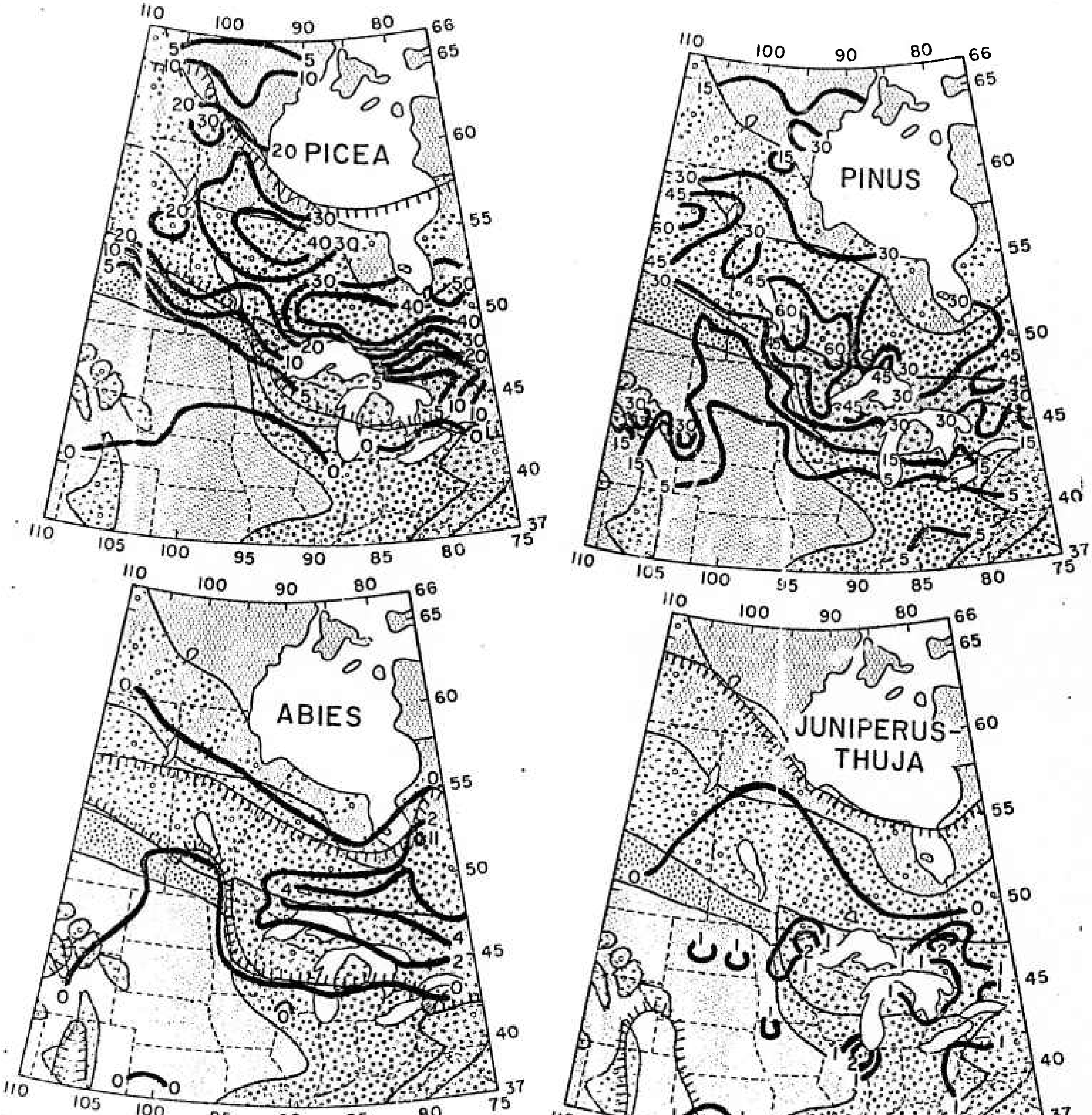
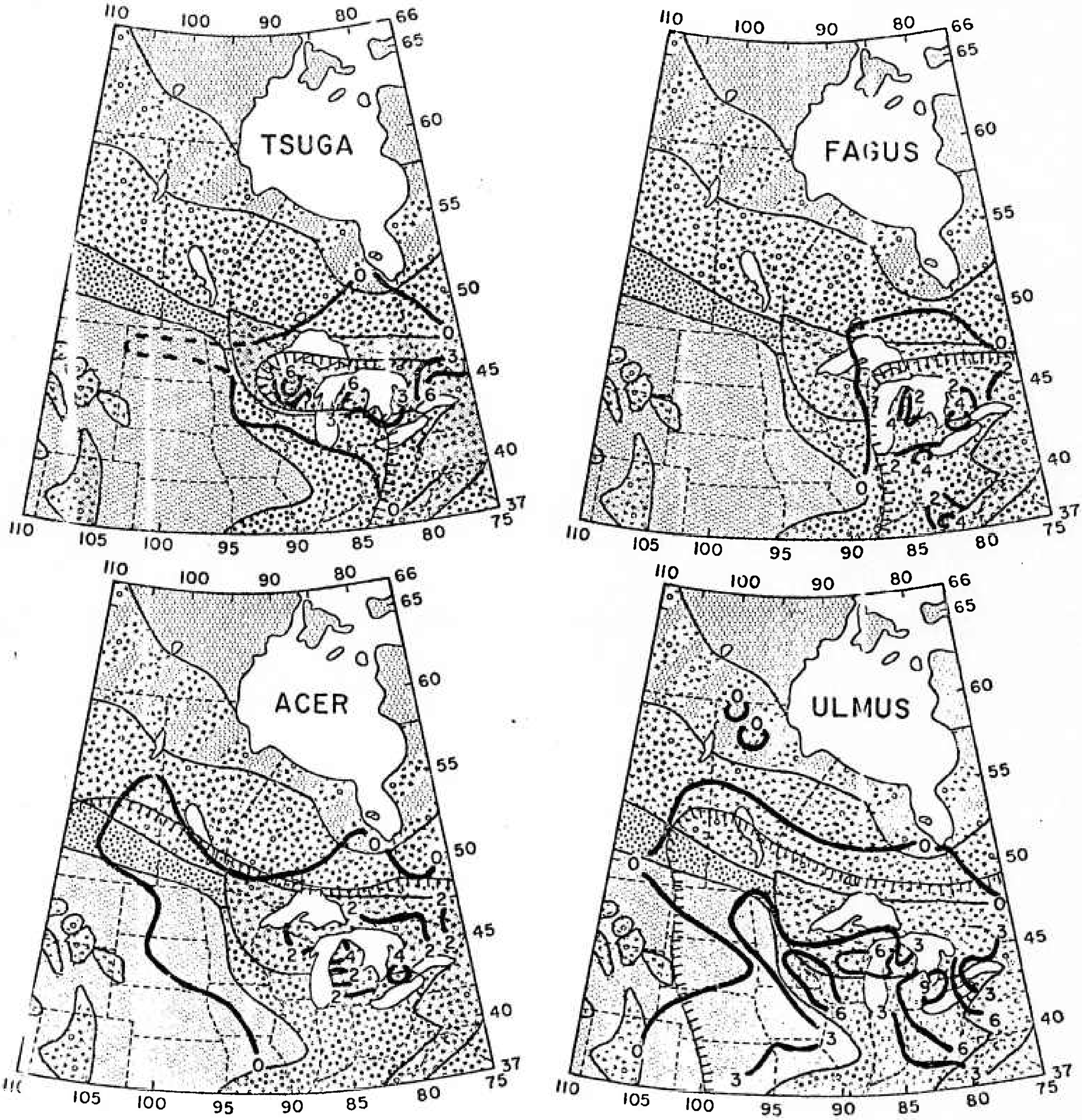

PICEA
PINUS
ABIES
JUNIPERUS-THUJA

Figure 3 Distribution of the pollen percentages in sediment samples of the modern pollen for *Tsuga* (hemlock), *Fagus* (beech), *Acer* (maple), and *Ulmus* (elm) pollen. Percentages are based on a sum of total pollen counted excluding aquatic pollen types. Isopleths are contours of equal pollen percentage.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ACER
ULMUS

Figure 4 Distribution of the pollen percentages in sediment samples of the modern pollen for *Quercus* (oak), *Carya* (hickory), *Ostrya-Carpinus* (hop-hornbeam), and *Fraxinus* (ash) pollen. Percentages are based on a sum of total pollen counted excluding aquatic pollen types. Isopleths are contours of equal pollen percentage.

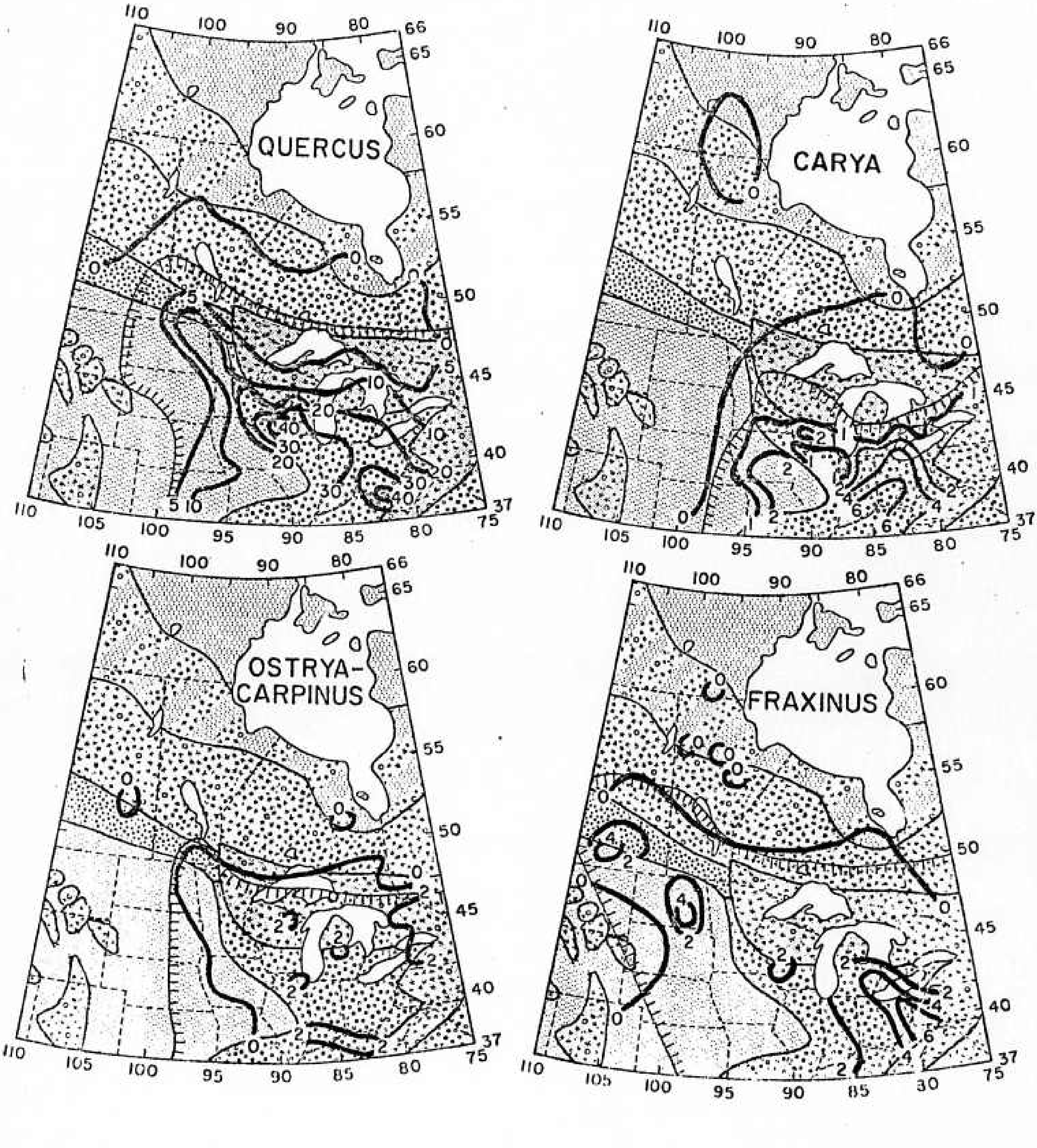

QUERCUS
CARYA
OSTRYA-CARPINUS
FRAXINUS

Figure 5 Distribution of the pollen percentages in sediment samples of the modern pollen for <u>Populus</u> (poplar), <u>Plantago</u> and <u>Rumex</u> (plantain and sorrel), <u>Ambrosia</u> (ragweed) and <u>Gramineae</u> (grass) pollen. Percentages are based on a sum of total pollen counted excluding aquatic pollen types. Isopleths are contours of equal pollen percentage.

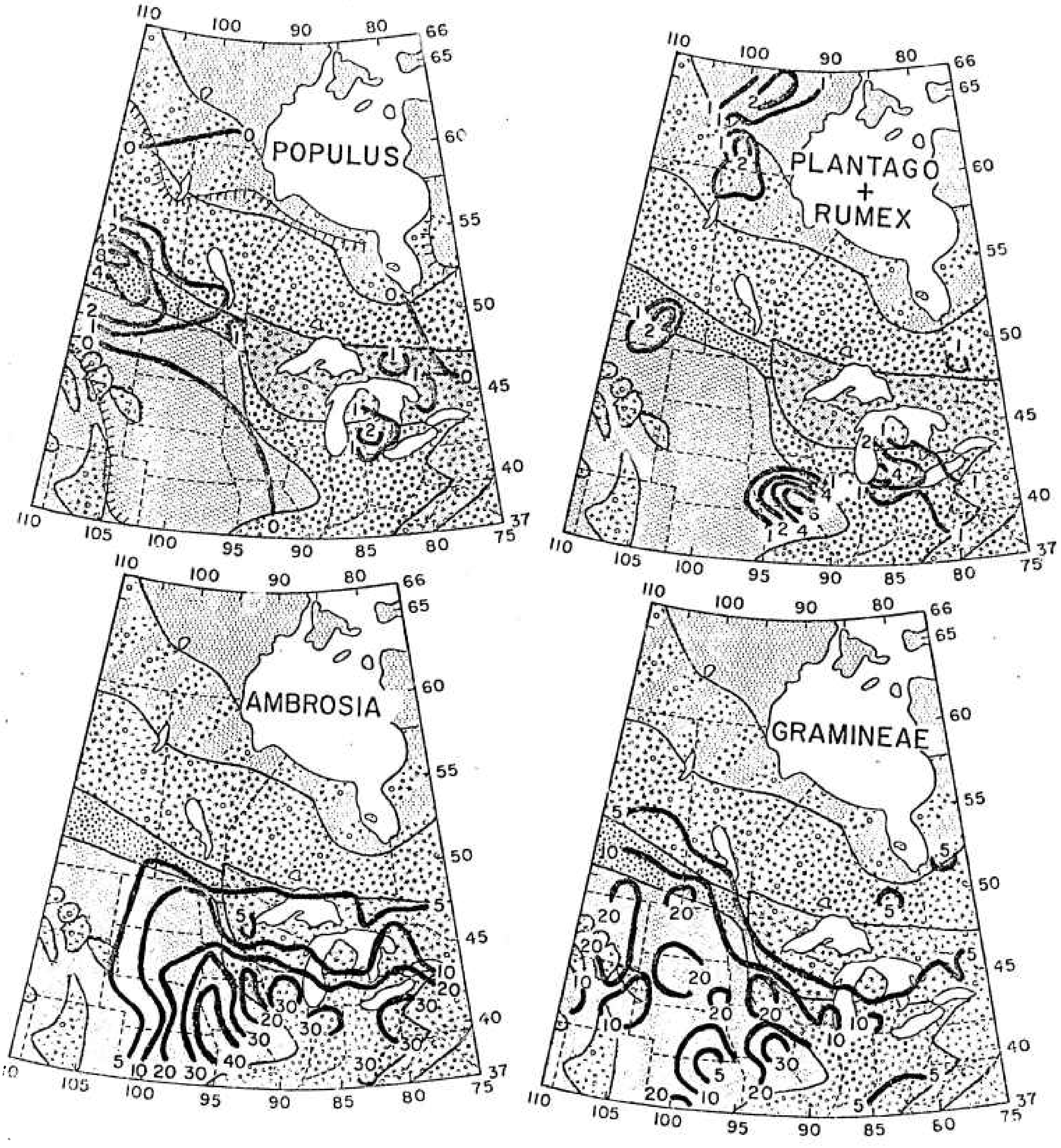

POPULUS
PLANTAGO
+
RUMEX
AMBROSIA
GRAMINEAE

Figure 6 Distribution of the pollen percentages in sediment samples of the modern pollen for Compositae (other-composite), Chenopodiineae (pigweed), Artemisia (sage), and prairie herb (grass, pigweed, other-composite, and sage) pollen. Percentages are based on a sum total pollen counted excluding aquatic pollen types. Isopleths are contours of equal pollen percentage.

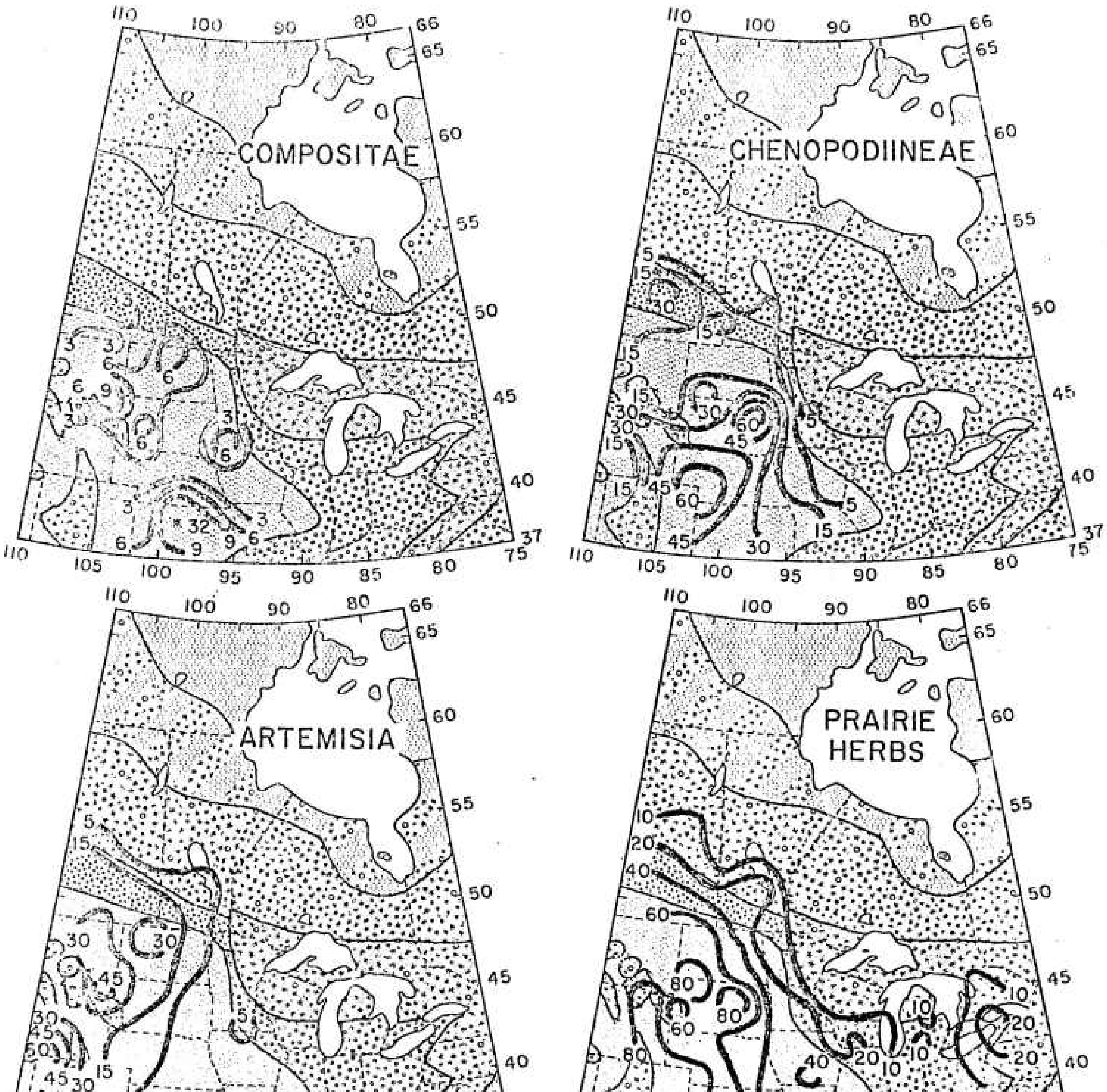

COMPOSITAE
CHENOPODIINEAE
ARTEMISIA
PRAIRIE
HERBS

Figure 7 Distribution of the scores of the first (P.C. 1), second (P.C. 2) third (P.C. 3) and fourth (P.C. 4) principal components.

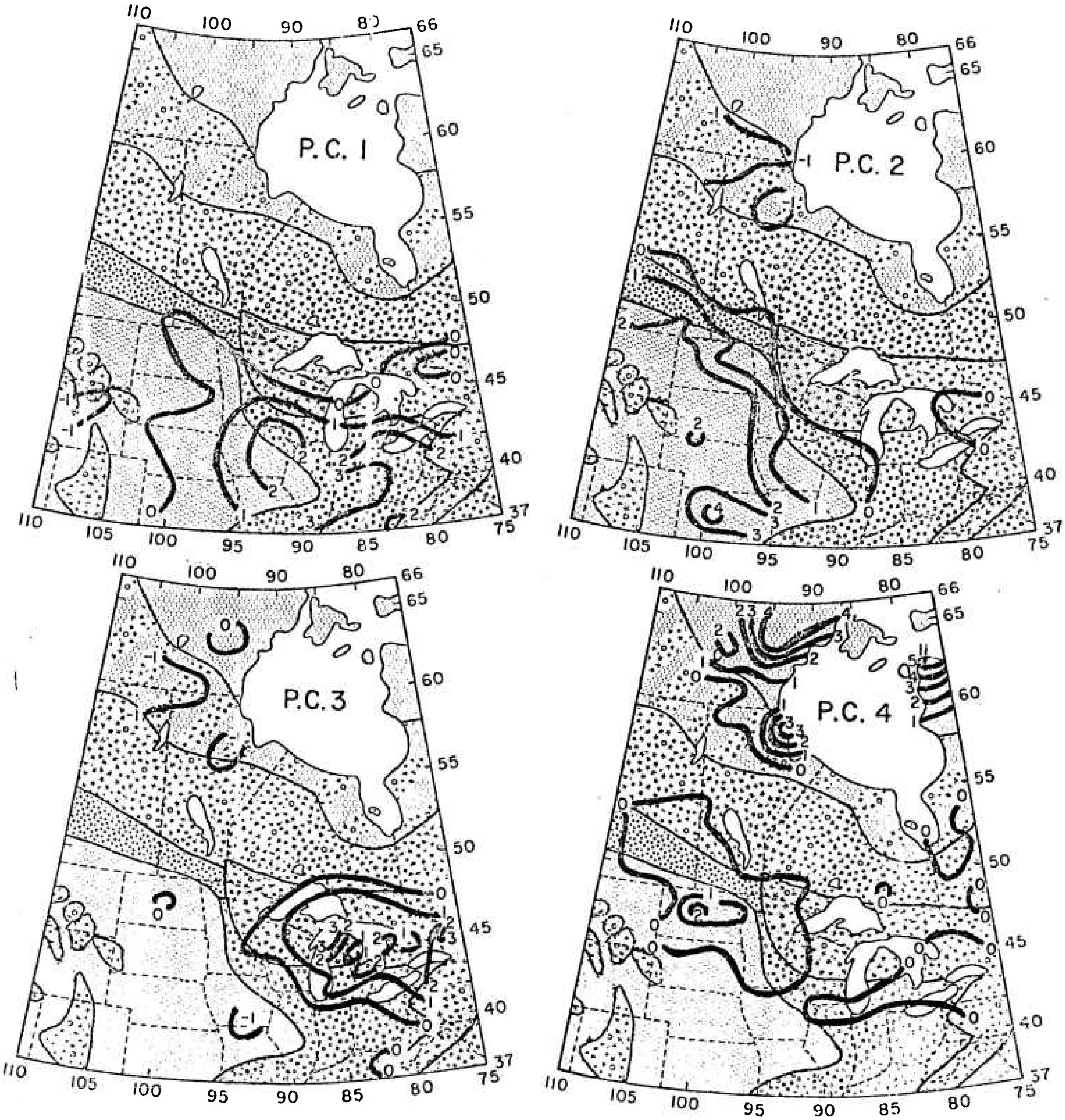
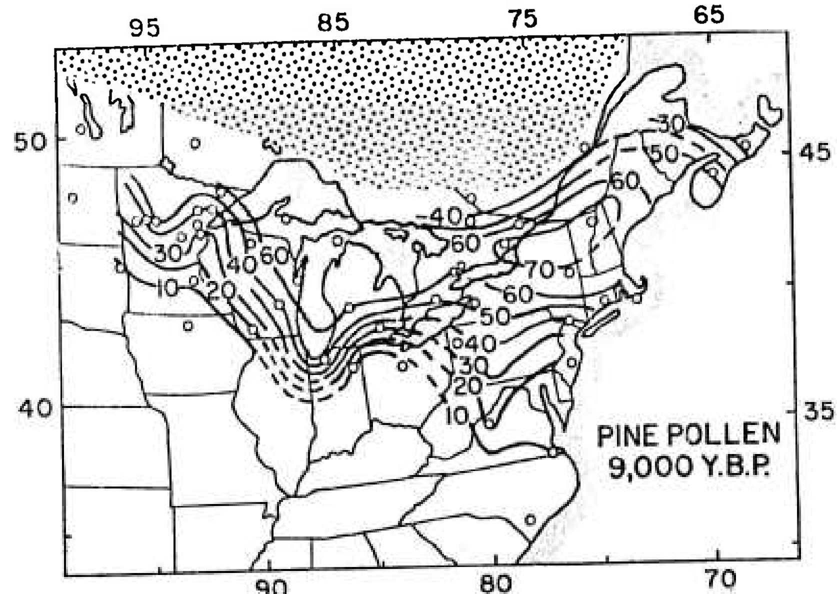

P.C. 1
P.C. 2
P.C. 3
P.C. 4

Figure 8 The distribution of pine pollen at selected times during the deglaciation of Eastern North America (Bernabo _et al._, 1974). Contours are lines of pollen frequency, expressed as a percent of total pollen. Control points representing radiocarbon dated cores are indicated by the dots. The approximate margins of the Laurentide ice-sheet are indicated by the stippled pattern (after Bryson _et al._, 1969).



95
85
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45
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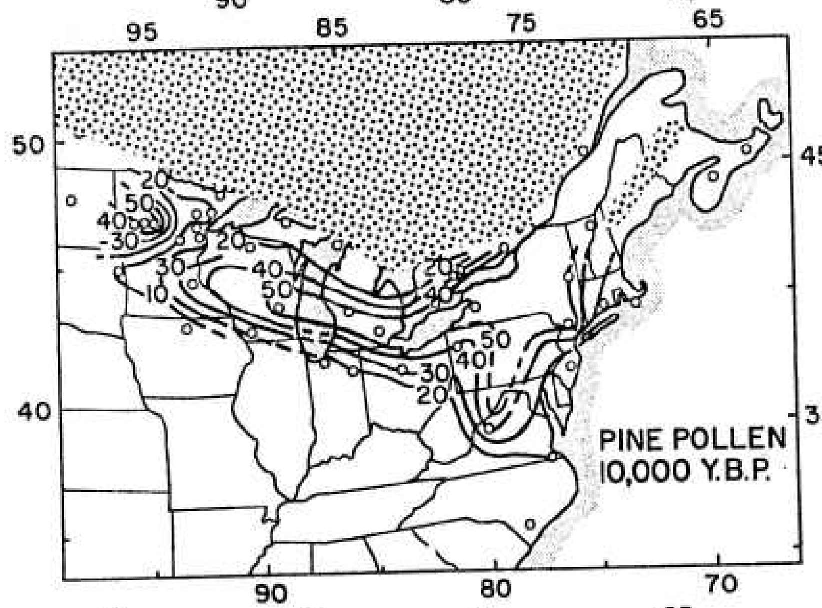
80
70
PINE POLLEN
9,000 Y.B.P.



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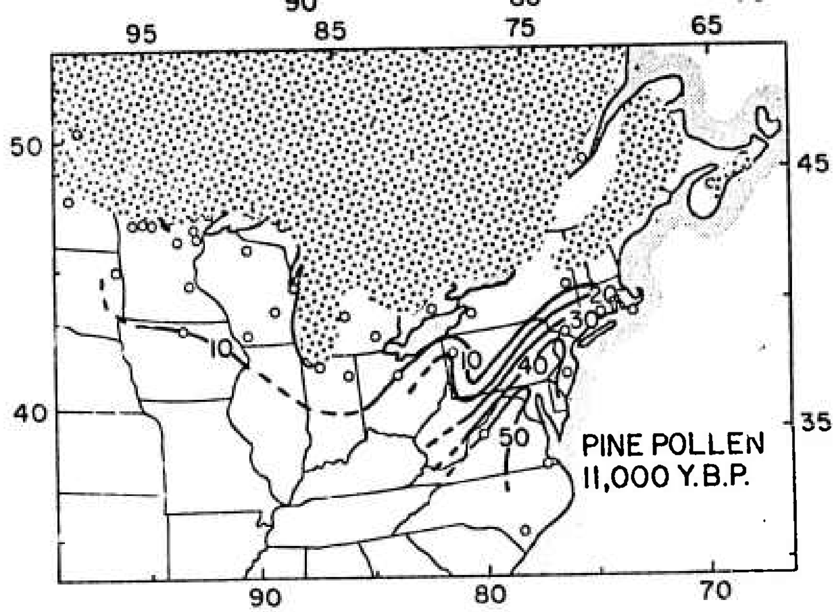
80
70
PINE POLLEN
10,000 Y.B.P.



95
85
75
65
50
45
40
35
90
80
70
PINE POLLEN
11,000 Y.B.P.

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A-1-a

APPENDIX A

WORKING PAPER FOR THE CONFERENCE ON TRANSFER FUNCTIONS SPONSORED BY CLIMAP AND ARPA AND HELD AT THE UNIVERSITY OF WISCONSIN, April 3-5, 1974

John Imbrie and Thompson Webb III

I. PREFACE.

Included in this working paper are definitions of key concepts and a list of problems. The definitions are subject to change and the list is incomplete. The aim of the paper is to improve communication; to provide an initial frame of reference within which to carry on debate; and to indicate the scope of the conference. We hope that it will aid the conference in achieving one of its goals: the design of experiments to answer basic questions in the field of transfer functions.

It would be a simple matter to broaden the conference, not only in the field of biologically based transfer functions, but also in the field of physically based transfer functions. Left out of consideration are taxonomically based work on benthic organisms, amino-acid techniques, and various approaches in the fields of glacial and peri-glacial geology, to name only a few. Both in writing this paper and organizing the conference, we have stressed a group of extensively tested techniques which are based on an algebraically homogeneous set of models and which provide continuous time-series and synoptic maps of late Pleistocene climates. Emphasis is placed first on techniques which monitor biological responses to climatic change (e.g. Imbrie

and Kipp, 1971; Webb and Bryson, 1972, Fritts et al., 1971); and second on the model developed by Shackleton and Opdyke (1973) which uses oxygen-isotope data from benthic and planktonic fossils to provide physically based estimates of changes in surface-water temperatures.

The mapping-potential of these techniques is particularly important, as noted in the Report of the May 1973 meeting of SCOR Working Group 40. The initiative for the Wisconsin Conference stems from this Report, in which Chairman Van Andel's summary states that there has been a "rapid development in recent years of mathematical and statistical techniques that have for the first time made it possible to quantify environmental parameters derived from the oceanic geologic record in a form suitable for input to dynamical models of the circulation. By providing quantitative environmental data for past conditions, it is not only becoming possible to model the dynamics of past circulations, but also to test existing models of the present circulation with regard to their power of explanation." The Report goes on to recommend the organization of "a small technical workshop on mathematical and statistical models that permit quantification of environmental data from the geologic record... and that the purpose of this workshop to review the various models, improve their compatibility, assess their strengths and weaknesses, evaluate the need for further methodological work, and produce a report that promotes wider use and understanding of these techniques."

II. DEFINITIONS.

Let the matrix X be a defined set of response properties, biotic or isotopic, measured over a defined realm of time and space. Let C be a set of physical parameters of climate, either marine or atmospheric, measured over the same time-space realm and assumed to be causally related to X. Let D be a set of other physical parameters of the system which are independent of C and which, together with C, completely control the response X. D includes such factors as dissolution and disturbance.

Then, if D = 0, the system consists of X, C, and a set of <u>ecological response functions</u> R_e:

$$X = R_e\ (C). \tag{1}$$

If $D \neq 0$, we must consider the <u>total response function</u> R_t:

$$X = R_t\ (C{:}D). \tag{2}$$

A fundamental problem of paleoclimatology is to find a set of <u>transfer functions</u> $\emptyset$ such that C can be estimated given X:

$$C = \emptyset\ (X). \tag{3}$$

Three points are worth noting: First, that $\emptyset$ is generally obtained by direct, empirical methods and not by inversion of R_e or R_t; second, that C is a matrix generally with more than one column; and third, that when $D \neq 0$ it is in principle still possible to derive $\emptyset$ if the rank of X is greater than that of (C:D).

The three elements of equation (3) are defined as the <u>monitoring system</u>. The system includes the <u>domain</u> X and the range C. The X and

C used to derive the transfer functions are the calibration data-set. The X to which the transfer functions are applied is the application data set. The main focus of the conference is on the monitoring system and the problems of obtaining and verifying Ø. Some attention must, however, be paid to the problems raised by equation (2); and the opportunities, such as those explored by Wolfgang Berger, for finding a function $Ø_d$ to estimate D given X.

III. OPTIMIZATION PROBLEMS.

In order to derive any transfer function, a number of choices must be made among alternative procedures (see Appendix 1). The problem therefore arises as to criteria for selecting the optimum set of procedures for a given monitoring system. We wish to choose the set which results in a transfer function which is the most robust against various types of distortion; the most precise in terms of laboratory error; and the most accurate. Several categories of problems can be recognized. For convenience in discussion, the categories are given letter designations and the problems are given a single numerical code and a brief name.

A. Algebraic problems. Given a particular domain X (in biotic work, a set of taxonomic categories or measures; and a calibration set of samples), the following problems represent choices among alternate procedures.

1. Covariance-adjustment problem. Is it wise to "eliminate the effect of latitude", for example.

2. Data-scaling problems. Various data-transformation options, including those spoken of as "R-mode" and "Q-mode" options, standardization, row-normalizing, and others.

3. Statistical-technique problem. Generally multivariate statistical technique or series of techniques should be used?

a. Eigenvector problem. Is it better to use "raw data" or linear combinations defined by eigenfunctions?

b. Rotation problem. If eigenvectors are used, should they be rotated? Does it make a difference?

c. Number of eigenvectors (canonical variates) problem. How many of the calculated eigenvectors or canonical variates derived from X or (X:C) should be retained for establishing the values of the transfer functions?

d. Regression problem. What procedure is best for writing Ø: standard least-squares regression; step-wise regression with elimination of less-useful terms; canonical correlation; etc.?

e. Linearity problem. Should Ø be assumed linear or non-linear? What is the nature of the non-linearity? If the non-linearity consists of simple squares and cross-products of X, then the problems are considered under this heading. If a more complex form of non-linearity is involved, the problem should be treated under section IV below.

4. Confidence-limit problems. How are these to be assigned? Empirically (i.e., with an independent set of test data); or theoretically (using principles of statistical inference and observations

on the calibration data-set)? What good are they?

B. Domain problems. A very large number of options are possible in defining the domain X, i.e., in specifying the kinds of variables to measure and the time-space realm in which to measure them. These options exist for both biotic and isotopic work.

5. Taxonomic problems. What species? what morphotypes? what combination of species? what combination of higher taxa? what habitat-selection? etc.

6. Operational problems. What census size? what sieve fraction? what criterion of countable specimen? what strew procedure?

7. Realm problem. What distribution of samples in time and space is to be used in the calibration data-set? This is a very important set of options, with implications extending into questions posed above under the linearity problem, for example, and several listed below as fundamental problems. One subproblem is to evaluate the method used by Luz (1973) in which the biological measures (the eigenvectors derived from foraminifera data comprising the sea-bed calibration-data-set) are defined by a data set of coretops and down-core fossils including the data in the down-core data-set to which the transfer functions are to be applied.

8. Inversion problem. Under what circumstances does Ø not exist? or possess limited accuracy (as is the case of a monospecific biota)?

9. No-analogue problem. Occurs when fossil values of certain taxa exceed the modern values used to derive the transfer functions.

C. <u>Range problems</u>. The selection and acquisition of valid estimates of the physical parameters arrayed in the matrix C are often of critical importance.

10. <u>Ground-truth problem</u>. How good are data on winter temperatures for the Southern Ocean, for example?

11. <u>Parameter-selection problem</u>. Which parameters are ecologically the most likely to influence the biotic response, or to be linearly-related to those which do? Which species are in isotopic equilibrium? Is it wise to use such parameters as atmospheric pressure, air-mass frequency, water mass frequency, dynamic height, or sigma-t? Should we use standard climatic variables or use linear combinations or complexes of these variables?

12. <u>Parameter-independence problem</u>. How much statistical independence among parameters is enough to provide a statistical basis for generating transfer functions which are capable of giving independent estimates of, say, salinity and temperature; or rainfall and temperature?

13. <u>Filter problem</u>. Many geological samples integrate the climatic inputs over many centuries or more. How can this effect be assessed?

14. <u>Lag problem</u>. Many biological and sedimentary monitoring systems exhibit significant lag in their responses to climatic change. How can this effect be assessed? How do we deal with this problem in selecting C for writing Ø?

15. <u>Seasonality problem</u>. How do we write ø when the calibration data-set for a single hemisphere crosses the thermal equator, so that the warmest temperatures occur in some places in August and in others in February? How do we estimate, say, an August sea-surface temperature map for the Indian Ocean, 18,000 years ago?

IV. FUNDAMENTAL PROBLEMS.

A number of problems require consideration at a different level from those listed under section III. Some represent questions which are unanswerable within the context of any transfer function based on a single biological group or isotopic system. Others represent a questioning of assumptions used in writing transfer functions. As listed below, several problems overlap.

16. <u>Validation problem</u>. How can we test the absolute accuracy of estimates of past climate? Four approaches have been or are being tried. Any others?

a. <u>Direct check</u>. In tree-ring work, meteorological records have been used to validate estimates of the recent past. Where else can this be done? Do these tests validate estimates from the more remote past?

b. <u>Comparison of two or more independent biologically-based transfer functions</u>. Radiolaria and forams, pollen and tree-rings, etc.

c. <u>Comparison of isotopic and biologically-based estimates</u>.

d. <u>Concordant estimates</u>, i.e., pairs with overlapping confidence intervals, encourage belief. Like discordant isotopic ages, discordant estimates (i.e., pairs with non-overlapping confidence intervals) identify important methodological problems or geological processes. Discordancy can result from the application of two transfer functions based on one organism group or based on more than one group.

e. <u>Synoptic consistency</u>. On an intuitive basis, the areal pattern and absolute range of synoptic maps can be evaluated. The advent of numerical simulation programs offers the possibility of making such intuitive evaluations both more rigorous, and more inclusive. Ultimately, proxy data from tree-rings, pollen, plankton, isotopes, and glacial geology must fit dynamically.

17. <u>Distortion problem (and opportunity)</u>. How effectively can transfer functions eliminate or surpress the effects of various processes which tend to distort the paleoclimatic signal? The other side of this coin is the opportunity to obtain useful estimates of the intensity of the distortion-producing processes themselves. Such processes include:

a. <u>Dissolution processes</u>

b. <u>Bottom-transport processes</u>.

c. <u>Cultural interference</u>

18. <u>Quality-control problem</u>. Can <u>a priori</u> criteria be formulated that can identify samples on which a given transfer function

will give invalid estimates? For instance, the criteria can be red flags of the form. "If species j exceeds abundance-level q, watch out!"

19. Evolution problem. If elements of the biota have evolved since the fossil deposit was formed, the calibration and application data-sets are non-homogeneous, and trouble lurks. Analagous problems occur where the calibration data-set is not wide enough to include the present range of fossil species (see 9, no-analogue problem).

20. Ecosystem-stability problem. What happens if links between various physical elements of the modern ecosystem (as captured in the calibration data-set) become uncoupled? If such an uncoupling occurs, does it result in an uncoupling between the biotic and physical realms? Do species-responses -- as captured in augmented and inverse form in Ø -- reflect the action of individual physical parameters themselves; or do these responses reflect the influence of these parameters as they are locked together in a particular pattern within the realm of an air- or water-mass?

21. Bio-thanatocoenosis problem. Are increases in accuracy and scope awaiting the mathematical modeling of isotopic and separate biological steps in the environment-plankton-fossil and environment-vegetation-pollen chains?

22. Transfer-function structure problem. What form of ϕ should be assumed? If non-linear, what kind of non-linearity (see 3e)? To what extent is the form dependent on data-scaling and the use of eigenvector transformations (2 and 3a)? Do different biological groups require different kinds of transfer functions?

V. TERMINOLOGICAL PROBLEMS

23. Is the term transfer function a good one. What about calibration function?

24. Faunal Index vs. faunal temperature-estimate, paleotemperature vs. isotopic temperature-estimate.

APPENDIX B

B-2-

CORRESPONDING PATTERNS OF CONTEMPORARY POLLEN AND VEGETATION IN CENTRAL NORTH AMERICA

T. WEBB III, Department of Geological Sciences, Brown University, Providence, R. I., 02912, U. S. A.
and
J. H. McAndrews, Department of Geology, Royal Ontario Museum, Toronto, Ontario, Canada

The increased use of modern pollen as a basis for interpreting fossil data requires compilation of the modern data in readily accessible form, such as maps of the relative frequencies of individual pollen types. This paper undertakes this task and presents maps incorporating over 600 pollen samples distributed throughout central North America (35-70°N, 75-110°W). Only data published after 1960 are included, and data from 50 sites are presented for the first time. The maps show well-marked changes in the pollen from plant formation to plant formation. For example, peaks in the values of sedge and birch occur in the tundra; high values of spruce appear in the boreal forest; high values of pine and birch appear in the mixed conifer-hardwood forests; high values of oak, elm, and hickory occur in the deciduous forest; and high values of herb pollen appear in the prairies. Where data permit, finer scale patterns in the vegetation are also evident, such as the difference between northern hardwood and pine forests. Principal component analysis of the pollen data helps to illustrate the patterns of covarying pollen types extant in the data. The pollen maps also indicate where additional samples need to be taken, such as north of 65°N, south of Hudson's Bay, and in the plains states. Joining the data from central North America together with the data from eastern North America compiled by R. B. Davis and Webb provides the initial core of data and maps needed to produce an "Atlas of Pollen Maps from Eastern North America."

APPENDIX C

THE CONTEMPORARY DISTRIBUTION OF POLLEN IN EASTERN NORTH AMERICA: CORRESPONDENCE WITH THE VEGETATION.

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and

T. WEBB III, Dept. of Geological Sciences, Brown Univ., Prov., R.I., U.S.A.

An understanding of the relationship between spectra of modern pollen and the distribution of vegetation on a continental scale greatly aids interpretation of late Quaternary assemblages of pollen. Maps for individual genera were constructed from 400 samples of modern pollen, including 55 previously unpublished samples, east of 90° in North America. The isofrequency contours or isopolls on these maps clearly reflect vegetational patterns both on the formation level and, where data are adequate, on a finer scale. Correspondence is particularly clear for several of the taxa (e.g. Cyperaceae, *Picea*, *Pinus*, *Betula*, *Quercus*, *Fagus*, *Tsuga*, and *Carya*) frequently used for climatic interpretation of the assemblages of fossil pollen. The maps also indicate need for increased numbers of surface samples in areas poorly sampled at present. A more complete understanding of the pollen-vegetation relationship awaits the availability of maps of quantities of each important taxon in the vegetation. Potential ambiguity in interpretations of fossil pollen, however, will remain as long as the spectra of modern pollen are recorded on a relative (percent) basis. As an initial step away from percentage data, the 55 new samples are expressed on a basis of number of grains/ml of lake sediment. These data show pollen concentration decreasing northward from the boreal forest into the region of tundra.

APPENDIX D

American Geophysical Union
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Abstract form for Washington D.C. Spring Meeting

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-D 2-

R. K. Matthews
Dept. of Geological Sciences, Brown Univ.
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Sea-level Fluctuation During the Past 150,000 Years. Pleistocene sea level is largely controlled by continental ice volume. Coral reef sequences and intervening subaerial exposure surfaces provide a history of sea-level fluctuations that can be dated by Th-230 throughout the last full glacial-interglacial cycle. Interglacial sea level 125,000 years ago stood 6m above today's. High stands of the sea between these interglacials occur at about 20,000-year intervals (105,000, 82,000, 60,000, and 42,000 years ago) and are separated by low stands of significant magnitude. The low stand 18,000 years ago was about 85m below present level; that between the 125,000 and 105,000 high stands reached 71 ± 11m below present level within 5,000 years of the previous high stand. Thus, the data imply that continental glaciers can build to substantial proportions quite rapidly.

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APPENDIX E

QUATERNARY SEA-LEVEL FLUCTUATIONS ON A TECTONIC COAST: NEW TH^{230}/U^{234} DATES FROM THE HUON PENINSULA, NEW GUINEA

By

A.L. Bloom — Cornell University, Ithaca, N.Y., U.S.A.
W.S. Broecker — Columbia University, New York, N.Y., U.S.A.
J.M.A. Chappell — Australian National University, Canberra, Australia
R.K. Matthews — Brown University, Providence, R.I., U.S.A.
K.J. Mesolella — Weaver Oil and Gas Co., Houston, Texas, U.S.A.

ABSTRACT

Emerged coral-reef terraces on the Huon Peninsula in New Guinea were reported in a reconnaissance dating study by Veeh and Chappell (1970). Age definition achieved was not good for several important terraces, and we report here a series of new Th^{230}/U^{234} dates, which further clarify the history of late Quaternary eustatic sea-level fluctuations. More than 20 reef complexes are present, ranging well beyond 250,000 years old : we are concerned with the seven lowest complexes. Major reef-building episodes dated by Th^{230}/U^{234} are reef complex I at 5 to 9 ka (ka = 1000 yrs), r.c. IIIb at 41 ka (4 dates) r.c. IV at 60 ka (4 dates), r.c. V at 80 ka (2 dates), r.c. VI at 106 ka (2 dates), and r.c. VII at 118 to 142 ka. Complex II was previously dated by C^{14} at 28 ka : this age has not yet been confirmed. The reef crests were built during or immediately before intervals of sea-level maxima, when rates of rising sea level and tectonic uplift briefly coincided. The culmination of each reef-building episode was only a few thousand years in duration, and multiple dates from the same reef complex generally group within the statistical errors of the individual dates.

Several methods can be used to estimate the altitude of each sea-level maximum relative to present sea level. The least complicated is to calculate mean tectonic uplift rate for each profile of the terraces, and use the mean rate to calculate the tectonic displacement of each dated reef complex on that profile. The difference between the present altitude of a reef complex and its calculated tectonic uplift gives the paleosea level at the time the reef grew. We estimate uplift rates for six surveyed sections by calibrating against

published paleosea level estimates from Barbados and elsewhere, *viz.*, 125 ka, paleosea at +6 m; 103 ka, - 15 m; 82 ka, - 13 m. For each section the individual uplift rates for reefs V, VI, and VIIb are within 5% of their section means. Using the mean rates, paleosea level estimates for reef crests II, IIIB and IV are made for each section. Consistency of estimates between sections is good, giving -28 m for the 60 ka paleosea level, around -38 m for the 42 ka level, and -41 m for the 28 ka level (age unconfirmed). Using the mean uplift rates, the 82 ka and 103 ka paleosea levels are also estimated for each section : all individual estimates are plotted graphically, and a sea level curve drawn. The reef stratigraphy indicates sea-level lowerings between each dated reef crest : the crests probably represent the interstadials of the Wisconsin (Würm, Weichsel) Glaciation, and intervening lower levels correpond to stadials. Since the last time of eustatic sea level higher than the present (about 125 ka), 5 sea-level maxima occurred at roughly 20 ka intervals, none being as high as the present.

Table I. Sample numbers, uranium radiochemistry, and ages of late Quaternary coral samples from the Huon Peninsula, New Guinea.

Field Sample No.	IDOE Lab. No.	Coral species (ident. by J. W. Wells)	total U(ppm)	U^{234}/U^{238}	Th^{230}/U^{234}	Age (10^3 yrs)
		Reef Complex I				
1	1351F	*Favia stelligera*	3.18 ± .06	1.12 ± .02	0.17 ± .01	~~21 ± 2~~ 9.5 ± .3
2	1351H	*Goniastrea retiformis*	2.68 ± .05	1.12 ± .02	0.087 ± .005	9 ± 0.5
[illegible]	1351I	*Hydnophora microconos*	2.48 ± .05	1.15 ± .02	0.051 ± .004	5 ± 0.4
[illegible]	1347H	*Leptoria phrygia*	2.64 ± .05	1.12 ± .02	0.087 ± .005	9 ± 0.5
[illegible]	1351D	*Favia stelligera*	3.18 ± .06	1.11 ± .02	0.085 ± .004	9 ± 0.4
		Reef Complex II				
[illegible]	1353B	*Favia sp.*	2.59 ± .06	1.11 ± .03	0.031 ± .002	~3
[illegible]	1355A	*Leptoria phrygia*	2.80 ± .08	1.12 ± .03	0.054 ± .003	~6
		Reef Complex III				
[illegible]	1353C	*Favia speciosa*	3.01 ± .06	1.11 ± .02	0.28 ± .02	35 ± 3
[illegible]	1353D	*Hydnophora exesa*	2.70 ± .05	1.13 ± .02	0.32 ± .02	41 ± 3
[illegible]	1347D	*Goniastrea parvistella*	2.54 ± .05	1.09 ± .02	0.32 ± .02	42 ± 3
[illegible]	1351J	*Lobophyllia corymbosa*	3.58 ± .07	1.12 ± .02	0.069 ± .004	7 ± 0.4
[illegible]	1351E	*Symphyllia nobilis*	3.23 ± .10	1.10 ± .03	0.32 ± .02	41 ± 3
		Reef Complex IV				
[illegible]	1347A	*Favia stelligera*	2.39 ± .05	1.11 ± .02	0.42 ± .02	58 ± 4
[illegible]	1351C	*Favia pallida*	2.37 ± .05	1.11 ± .02	0.43 ± .02	61 ± 4
[illegible]	1351A	*Acropora sp.*	4.06 ± .08	1.16 ± .02	0.38 ± .02	45 ± 3
[illegible]	1351G	*Favia pallida*	3.12 ± .06	1.11 ± .02	0.41 ± .02	57 ± 4
[illegible]	1347E	*Hydnophora microconos*	2.92 ± .06	1.13 ± .02	0.46 ± .02	66 ± 4
		Reef Complex V				
3	1347F	*Platygyra lamellina*	2.63 ± .05	1.13 ± .02	0.43 ± .02	60 ± 4
12	1347B	*Porites lutea*	3.49 ± .07	1.10 ± .02	0.54 ± .01	84 ± 2
13	1353E	*Goniastrea pectinata*	2.94 ± .06	1.11 ± .02	0.55 ± .02	85 ± 4
		Reef Complex VI				
[illegible]	1353A	*Favia speciosa*	2.73 ± .06	1.12 ± .02	0.63 ± .03	106 ± 7
	1347C	*Hydnophora microconos*	3.45 ± .07	1.09 ± .02	0.63 ± .02	107 ± 6
		Reef Complex VII				
	[illegible]	*Porites lutea*	2.90 ± .06	1.06 ± .02	0.74 ± .02	142 ± 8

TABLE 2. MINERALOGY AND MINOR-ELEMENT CHEMISTRY OF LATE QUATERNARY CORAL SAMPLES FROM THE HUON PENINSULA, NEW GUINEA (SEE TEXT FOR DISCUSSION).

Field Sample No.	Disposal and comments (see footnotes)	Fraction of total carbonate			Minor elements ($^0/_{00}$ in solid)	
		aragonite	high-Mg calcite	low-Mg calcite	Sr	Mg
1	1	1.00	-	-	6.50	2.64
2	1	1.00	-	-	6.20	1.30
2	1	1.0	-	-	6.66	1.15
3	1	.99	-	.01	6.60	2.40
4	1	1.00	-	-	6.70	2.26
5	2, a	1.00	-	-	6.80	3.06
6	1	1.00	-	-	.80	1.00
7	1	.97	-	.03	6.30	1.52
8	1	.99	-	.01	7.04	1.14
12	1	.99	-	.01	7.20	1.12
14a	2,3,c	.88	-	.12	8.01	1.33
14a	2,3	.90	-	.10	6.90	1.28
14b	1,3	.97	-	.03	7.10	1.20
15	1	.99	-	.01	7.16	1.74
16	2,d	.93	-	.07	6.70	2.36
16	2,d	.95	-	.05	6.60	1.78
17	2,3,a,e	.95	-	.05	6.40	4.50
18	2,3,a	.98	-	.02	6.80	2.16
20	1	.97	-	.03	7.56	1.31
21	1,3,f	.98	-	.02	6.90	1.15
23	2,a	.92	-	.08	6.20	1.40
24	1,3	.99	-	.01	7.20	1.60
25	1,3	.99	-	.01	6.50	1.14
26	1	.98	-	.02	7.94	1.74
28	1	1.00	-	-	6.30	1.24
29	1	.99	-	trace	7.10	1.08
30	2	.92	-	.08	6.50	1.09
31	2,a	.85	.10	.05	6.60	7.20
33a	2,3,g	.92	.06	.02	5.80	5.00
33b	1	1.00	-	-	6.40	1.42
37	2	.66	-	.34	4.50	0.75
37	2	.70	-	.30	5.40	1.04
38	1,3,f	.99	-	.01	6.40	1.22

Table 2 (Contd.)

39a	2,3,c	.90	-	.10	6.20	1.90
39b	1	.99	-	.01	6.70	1.36
39b	1	.99	-	trace	7.10	1.07
40	1	1.00	-	-	6.40	1.24
41	2,a,b	.96	-	.04	6.20	1.22
42	1	.99	-	trace	7.60	2.06
43	2	.92	.04	.04	7.60	2.40
44	2,3,a,c	.94	-	.06	6.44	1.92
45	1	1.0	-	-	7.56	1.29
46	2,a,b	.95	-	.05	6.70	2.04

1 dated (see table 1 for additional data)

2 rejected for dating

3 thin section prepared

a void-filling crystals

b void-filling micrite

c calcite crust in corallites

d micrite coating in corallites

e borings

f hairline of clear calcite crust

g internal sediment and aragonite needles

TABLE 3. MEASURE OF REEF CREST ELEVATIONS (m), AND UPLIFT RATES (m/10^3 YRS), CALCULATED USING ASSUMPTIONS GIVEN IN TEXT:

TERRACE	Age, Initial Elevation	KANZARUA	BLUCHER	KWAMBU	NAMA	SAMBERO	KAMBIM
VIIb	124 ka, +6 m	330, 2.62	280, 2.21	215, 1.69	160, 1.24	150, 1.16	120, .91
VI	103 ka, -15 m	250, 2.57	215, 2.23	160, 1.69	115, 1.26	110, 1.21	93 1.05
V	82 ka, -13 m	190, 2.48	155, 2.05	117, 1.58	90, 1.25	80, 1.13	60 .89
mean rate		2.56	2.16	1.65	1.25	1.17	.94
predicted height of reef I (m) *		10.2	8.6	6.6	5.0	4.7	3.8
actual height of reef I		15	10	6	5	5	2.5

* calculated as uplift rate x 4 ka; see text.

TABLE 4. MEASURE OF REEF CREST ELEVATIONS (m), AND RECONSTRUCTED PALEOSEA LEVELS (m), USING MEAN UPLIFT RATES FROM TABLE 3, FOR TERRACES II TO IV.

TERRACE	Age, x 1000 yr	KANZARUA	BLUCHER	KWAMBU	NAMA	SAMBERO	KAMBIM	Mean (m)
IV	60	125, -29	-,	70, -29	48, -27	-,	28, -28	-28
IIIa *		90	65	42	-,	-,	-,	
	50 max.	-38	-43	-42				see text
	40 min.	-12	-21	-26				
IIIb	40	70, -32	41, -45	28, -38	10, -40	10, -37	-,	-38
II	28	30, -42	18, -42	7, -40	-,	-,	-,	-41

NOTES :
* As IIIa has not been dated directly, paleosea levels are calculated for upper and lower age limits - see text.

-, Terrace crest uncertain; or no satisfactory height measurement.

CAPTIONS FOR FIGURES AND TABLES

Figure 1. Location and generalized physiography of the Huon Peninsula, New Guinea. Spot heights in meters; rainfall in inches.

~~Figure 2.~~ Omitted Three aerial views of the Huon Peninsula emerged reef terraces (Chappell, 1972). Variations in elevations of reef complex III and VII are a guide to the differential uplift of the region. Note : altitudes on uppermost photo are barometric estimates only; other heights are surveyed.

Figure 3. Models of the facies geometries in barrier and fringing reefs, showing the changes associated with submergence and emergence (a) Landward-dipping internal facies boundaries associated with submergence. (b) Changes in reef morphology during submergence from (1) fringing reef, (2), (3) barrier reef with lagoon and fringing lagoon-shore reef, (4) barrier reef with lagoon and patch reefs. (c) Cliffs, notches, and fringing reef associated with emergence followed by relative stillstand.

Figure 4. Six surveyed profiles of the Huon Peninsula emerged reef terraces. Reef complexes I to VII are shown by Roman numerals. Sample numbers are shown as near as possible to their collection localities.

Figure 5. Late Quaternary paleosealevels based on estimates from New Guinea and elsewhere.

Table 1. Sample numbers, taxonomy, radiochemistry, and ages of late Quaternary coral samples from the Huon Peninsula, New Guinea.

Table 2 Mineralogy and minor-element chemistry of late Quaternary coral samples from the Huon Peninsula, New Guinea.

Table 3. Measured elevations and calculated uplift rates for reefs V, VI, VIIb, for six surveyed traverses.

Table 4. Measured elevations and paleosea level estimates, using uplift rates from Table 3, for reefs II, IIIb, IIIa, IV, for six traverses.

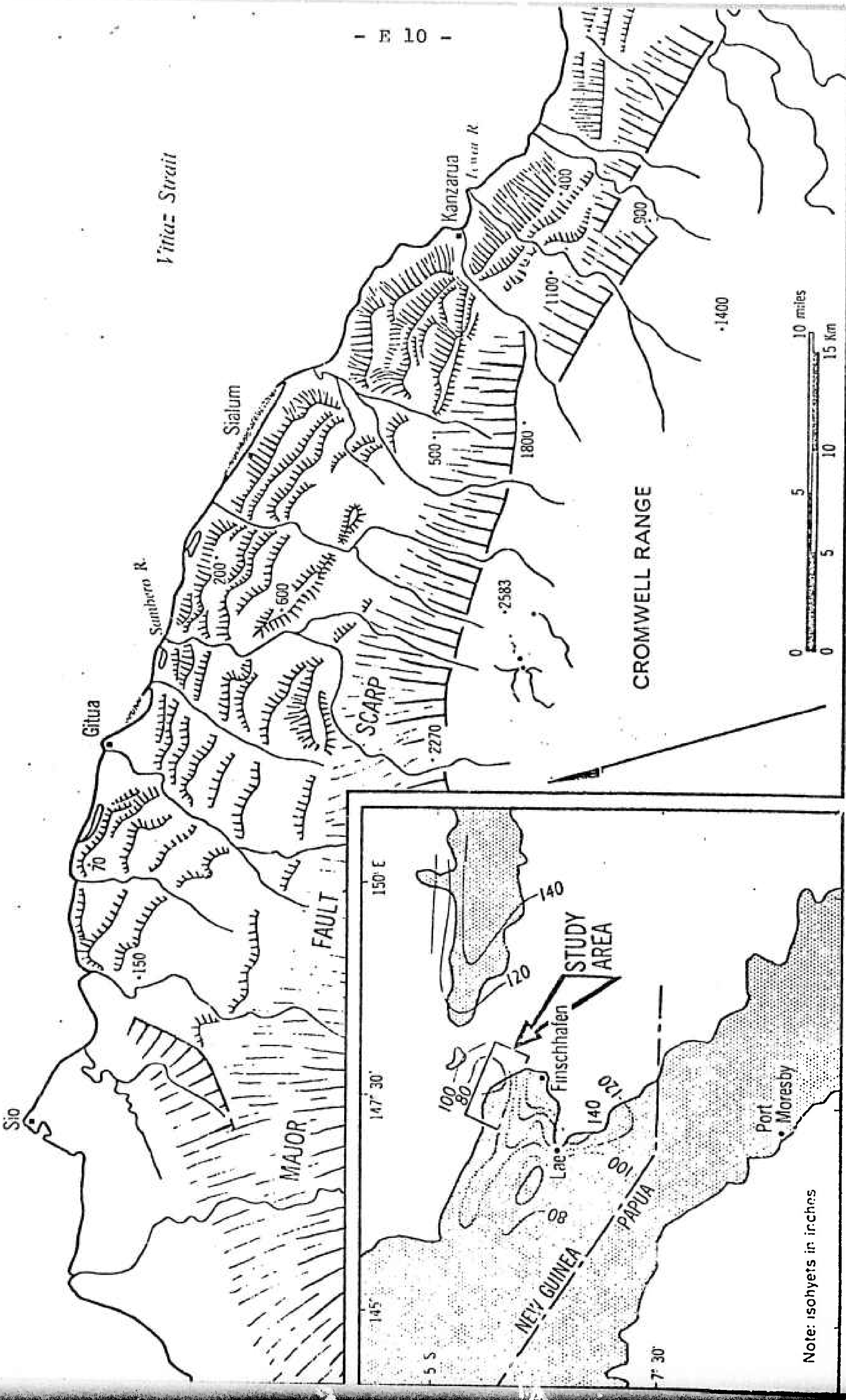

Vitiaz Strait
Sio
Gitua
Sialum
Kanzarua
MAJOR
FAULT
SCARP
CROMWELL RANGE
70
•150
200
600
500
1800
•2583
•2270
400
900
1100
•1400
0
5
10 miles
0
5
10
15 Km
150° E
147° 30'
145°
5 S
7° 30'
STUDY AREA
Finschhafen
Lae
Port Moresby
NEW GUINEA
PAPUA
140
120
100
80
Note: isohyets in inches

Fig. 1

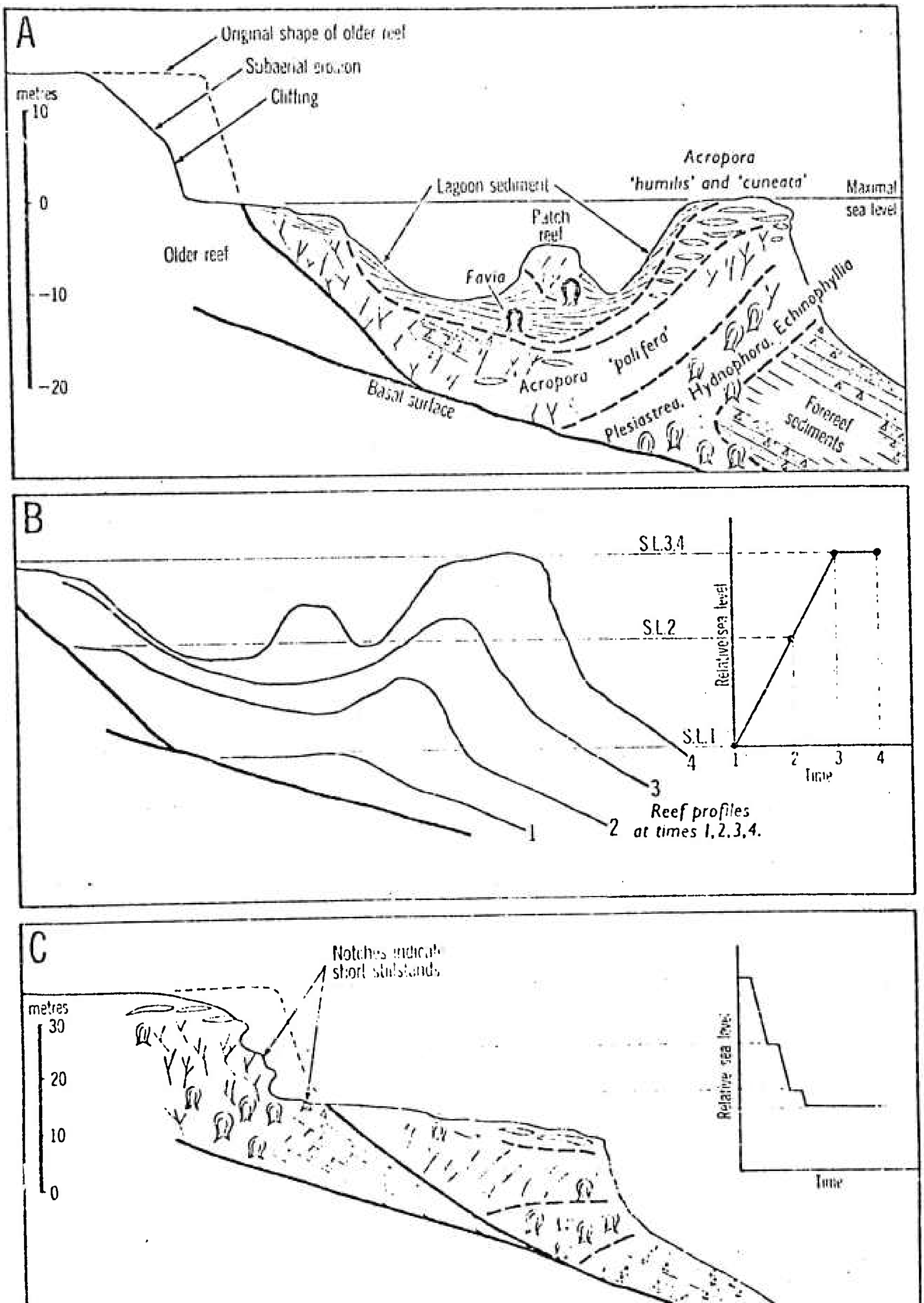
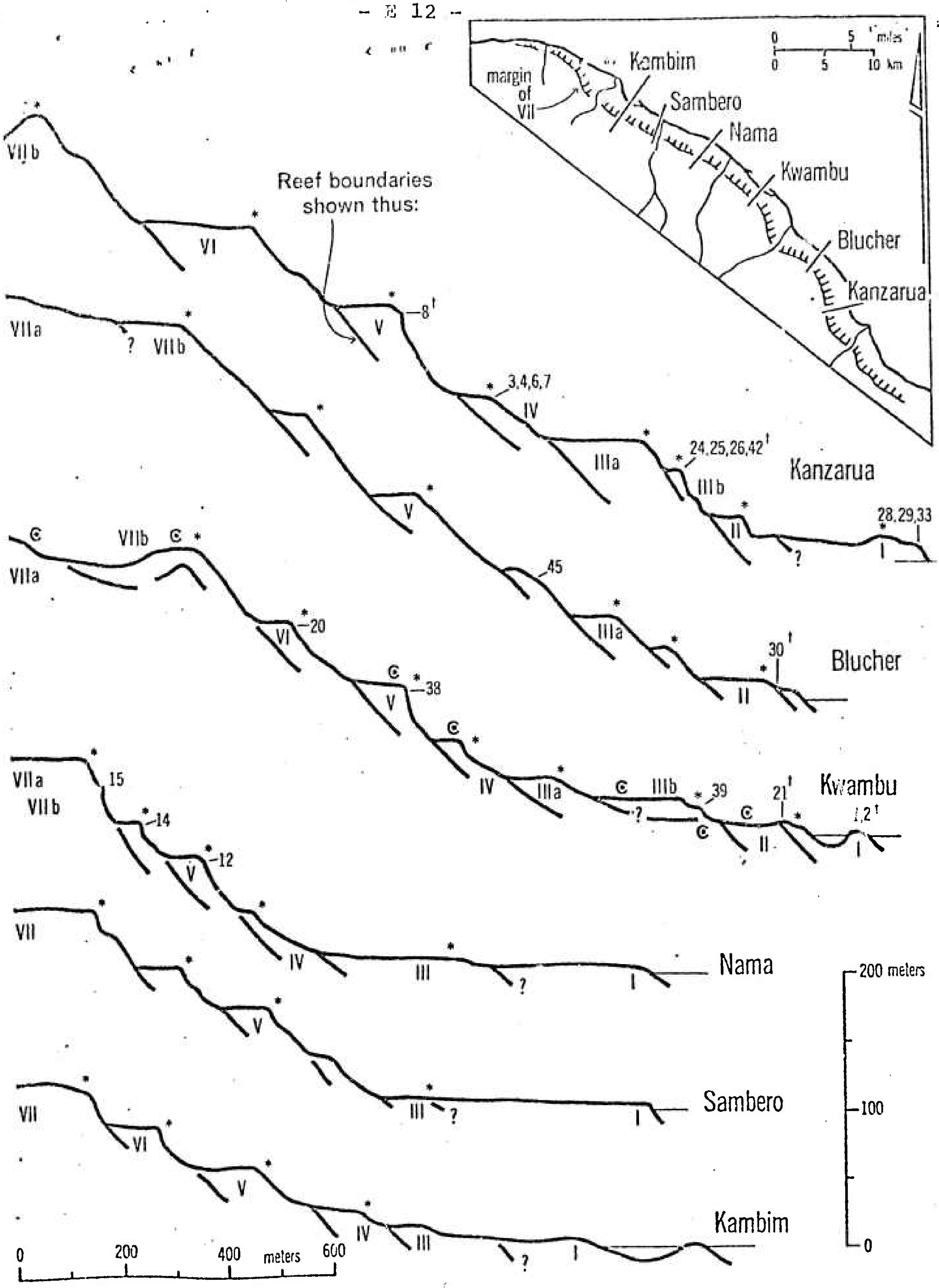

A
Original shape of older reef
Subaerial erosion
Cliffing
metres
10
0
-10
-20
Older reef
Lagoon sediment
Patch reef
Favia
Acropora
'humilis' and 'cuneata'
Maximal sea level
'palifera'
Acropora
Basal surface
Plesiastrea, Hydnophora, Echinophyllia
Forereef sediments
B
S.L.3,4
S.L.2
S.L.1
Relative sea level
Time
Reef profiles at times 1,2,3,4.
C
Notches indicate short stillstands
metres
30
20
10
0
Relative sea level
Time

Fig. 3.



VI	Reef complex number
*	Theodolite survey point
32	Field sample from traverse, as shown.
41†	Field sample from near, but not on, traverse

Fig 4

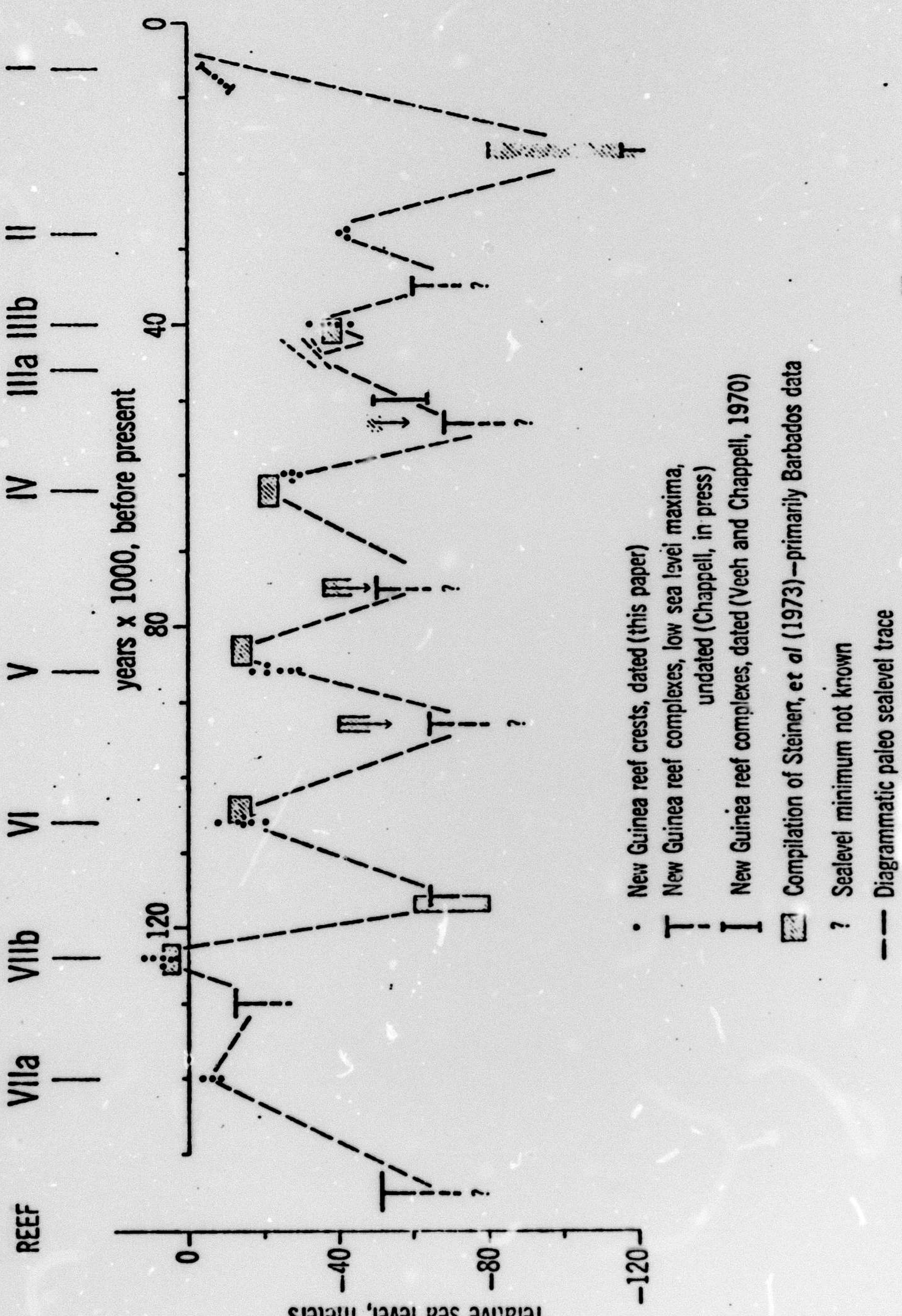
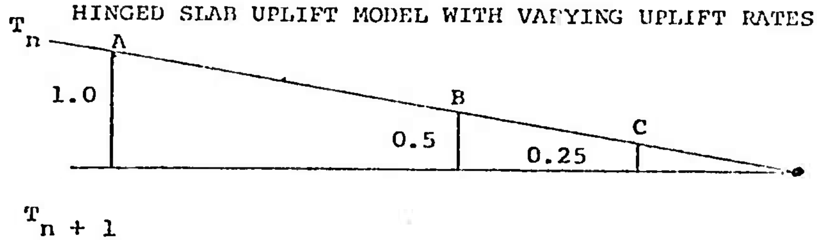

REEF
VIIa
VIIb
VI
V
IV
IIIa
IIIb
II
I
years x 1000, before present
0
40
80
120
relative sea level, meters
0
-40
-80
-120
?
New Guinea reef crests, dated (this paper)
New Guinea reef complexes, low sea level maxima, undated (Chappell, in press)
New Guinea reef complexes, dated (Veeh and Chappell, 1970)
Compilation of Steinen, et al (1973)—primarily Barbados data
? Sealevel minimum not known
Diagrammatic paleo sealevel trace

Fig 5.

APPENDIX F

HINGED SLAB UPLIFT MODEL WITH VARYING UPLIFT RATES



Example

Time interval	Rate of Uplift A	B	C
T_1 to T_2	2.0	1.0	0.5
T_2 to T_3	1.0	0.5	0.25
T_3 to T_4	4.0	2.0	1.0
$\bar{R}$ =	2.33	1.167	0.583

Input to model: $R_{A_n} = c \cdot \bar{R}_A$, and likewise for traverses B and C		Estimated from rate differences: $(R_A - R_B)_n = c(R_A - R_B)_{ave.}$ and likewise for $(R_A - R_C)$ and $(R_B - R_C)$		
		$(R_A - R_B)_n$	$(R_A - R_C)$	$(R_B - R_C)$
Time interval	c	c	c	c
T_1 to T_2	.857	.857	.857	.857
T_2 to T_3	.429	.429	.429	.429
T_3 to T_4	1.715	1.715	1.715	1.715
$\bar{c}$ =	1.000	1.000	1.000	1.000

Thus, a set of coefficients (c) constituting a variable uplift model can be estimated from the rate differences $(R_A - R_B)_n$... Knowing R_A.. from the age and elevation of any one terrace of known sea level, estimates of all other sea levels (n) can be calculated by application of the uplift model to each traverse.

R. K. Matthews, March 1974

APPENDIX G

The Geological Society of America, Inc.
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-G-2

ABSTRACT FORM – 1974 ANNUAL MEETING
Miami Beach, FL. Abstracts MUST reach GSA Headquarters by June 15, 1974.*

SEA LEVEL DYNAMICS AT THE END OF THE LAST INTERGLACIAL: INFERENCES FROM 125,000 YEAR OLD REEF, BARBADOS, W. I.

Mangion, Stephen, and Matthews, R. K., CLIMAP, Dept. Geol. Sci., Brown University, Providence, R. I. 02912

Spatial relationships of coral taxa within the 125,000 year old Barbados III reef indicate sea level during the Pangaion maintained its maximum position for less than 5,000 years before abruptly and rapidly receding. Development of a reef facies geometry was controlled by the rate of (1) tectonic uplift, (2) reef carbonate production, and (3) sea level fluctuation. Analyses of cross-sections and borehole samples of the reef have been used to interpret the following sea level history. Early phases of reef accretion are marked by nearly vertical contacts between adjacent facies indicating a rapid sea level rise. Additional diagenetic evidence from borehole samples indicates this rise started at least 20 m below present sea level. Later phases are marked by a maximum of 40 m of reef progradation with sea level at or near its highest elevation for no more than 5,000 years. Finally the reef crest facies moved downslope as reef construction was progressively halted by a sea level lowering of 5 - 10 m/1,000 yrs. The rate of sea level lowering indicated by this study implies that post Pangaion glacial growth was rapid.

CLASSIFICATION

Specify one. If more than one category is appropriate, indicate order of preference by numbers. Be as specific as possible.

crystallography
geochemistry

geochronology

geology
archeologic
economic

education
engineering
environmental
general
historical
lunar
marine

mathematical
1. Pleistocene
structural

geomorphology

geophysics

geomagnetism
geoscience information
hydrogeology
mineralogy

paleontology
micro
invertebrate
vertebrate

petrology
igneous
metamorphic
sedimentary
planetology

sedimentology
stratigraphy
tectonics
volcanology
2. Emiliani Sym.?
OTHER

Oral ☒ Discussion ☐ Symposium ☐ ______________________
(title of symposium)*

Speaker Stephen Mangion

Indicate authors who are not GSA members –

Percentage of paper previously presented 0, where and when –

Other abstracts submitted to this meeting (an individual may author or co-author no more than two uninvited abstracts and may present only one paper) ______________________

Only 2-x-2-inch slides can be projected, and only one screen will be available during a technical session.

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I will be available to serve as a co-chairman for a technical session on or concerning ______________________

Temporary address of senior author, with dates (for correspondence purposes) Department of Geological Sciences, Brown University, Providence, R. I. 02912

Please note, all symposium abstracts (originals plus two copies) must be sent to the organizers of the respective symposia by ... 1, 1974, not to GSA Headquarters.

APPENDIX H

Section of Meteorology

ICE AGE STRUCTURE AND DYNAMICS (M)

Richmond Room — Monday 0845h

Chairmen: JAMES D. HAYS (Lamont-Doherty Geological Observatory, Palisades, New York) and J. MURRAY MITCHELL, JR. (NOAA, Environmental Data Service, Silver Spring, Maryland)

M1

James D. Hays
Lamont-Doherty Geological Observatory, Palisades, N. Y. 10964

Chronology of Ice Age Climates: The Last Million Years. Recent isotopic evidence from deep-sea cores and other evidence has established a major climatic cycle with an average duration of about 100,000 years. Studies by Shackleton and Opdyke of the oxygen isotope ratio of both planktonic and benthonic foraminifera for a long Pacific core indicate that in the western equatorial Pacific the isotopic variations are due mostly to changes in world ice volume. The δO^{18} maxima and minima during the past million years are similar, suggesting that there were at least nine major advances and retreats of glacial ice during the last million years and these advances and retreats were of similar magnitude. This is in agreement with the mapping of glacial deposits on land which indicate similar ice limits for different glaciations. For at least the last 500,000 years, the glacial-interglacial cycle is clearly reflected in various long climatic records, including the soil sequence in central Europe, sea-surface temperature and salinity, and the chemistry of Pacific bottom waters. The thermal response to this cycle is in general simultaneous in all oceans and in the N. and S. Hemispheres. But where our chronology is most accurate (the past 30,000 years) the response of ice sheets and high-latitude oceans in the N. Hemisphere lag the thermal response in the tropics.

M2

R. K. Matthews
Dept. of Geological Sciences, Brown Univ. Providence, R.I. 02912

Sea-level Fluctuation During the Past 150,000 Years. Pleistocene sea level is largely controlled by continental ice volume. Coral reef sequences and intervening subaerial exposure surfaces provide a history of sea-level fluctuations that can be dated by Th-230 throughout the last full glacial-interglacial cycle. Interglacial sea level 125,000 years ago stood 6m above today's. High stands of the sea between these interglacials occur at about 20,000-year intervals (105,000, 82,000, 60,000, and 42,000 years ago) and are separated by low stands of significant magnitude. The low stand 18,000 years ago was about 85m below present level; that between the 125,000 and 105,000 high stands reached 71 ± 11m below present level within 5,000 years of the previous high stand. Thus, the data imply that continental glaciers can build to substantial proportions quite rapidly.

M3

George H. Denton
Dept. of Geological Sciences, University of Maine, Orono, Maine 04473
Sponsor: R.K. Matthews

Ice-age Ice Sheets: Their Global Distribution 18,000 years Ago and Subsequent Disintegration. Reconstruction of global ice-cover for numerical modelling experiments of ice-age atmospheres emphasizes that at the last glacial maximum 21,000-14,000 years ago large ice sheets were restricted to Greenland, Antarctica, northern North America, northwestern Europe, and the Taymyr Peninsula in northern Siberia. Elsewhere, surprisingly little ice formed. Beginning 14,000 years ago a widespread and dramatic glacier collapse led to the disappearance, or reduction to present size, of all ice sheets outside of Antarctica by 6,000-10,000 years ago. A particularly spectacular event involved the rapid disintegration of the extensive central portion of the Laurentide Ice Sheet about 8,000 years ago. Minor periods of glacier expansion, superimposed on these major events, occurred at 2,500 year intervals. The East Antarctic Ice Sheet, which rests on a continental base, has remained relatively stable; but the West Antarctic Ice Sheet, based below sea level, has been collapsing through at least the last 12,000 years from an extended position in the Ross and Weddell Seas. If this collapse continues, as seems likely, future sea level will rise as much as 4.5 m, perhaps at a rapid rate.

M4

W. F. Ruddiman
U.S. Naval Oceanographic Office, Washington, D. C. 20373
Sponsor: R. K. Matthews

Time-Space Pattern of Climate Change in the Atlantic Ocean. For sediments beyond the range of radiocarbon dating, correlative horizons in deep-sea sediments are interpreted from variations in fauna, flora, and sediment chemistry. The resulting correlation networks have been used to construct a transect of the Atlantic, which shows watermass-migrations during the last 200,000 years across more than 20° of latitude. At peak glaciations, polar water moves south to 42°N where an abrupt, east-west frontal system separated an expanded cyclonic subpolar gyre from the subtropical gyre. Comprehensive geographic core coverage indicates that during the last deglaciation (18,000-6,000 years ago) the polar front retreated northwestward from its glacial alignment. In the subpolar N. Atlantic a 9,300-year-old ash layer permits a synoptic reconstruction which defines an oceanic front along 48°N, apparently created by a maximum wind-stress axis anchored along and downstream from the southern margin of the Laurentide ice sheet. Similarly, the abrupt gradient and zonal alignment of the ice-age polar front (18,000 years ago) suggests that this was in part established by the focusing of an axis of maximum westerly winds along the narrow latitudinal band lying between the southern margins of the Laurentide and Scandinavian ice sheets.

World-Ocean Isotherm Map During an Ice-age, 18,000 Years Ago. One aim of the CLIMAP project is to reconstruct the surface oceanography of the world ocean for particular times during the past 700,000 years. Planktonic fossils from chronostratigraphic samples are processed using multivariate transfer-function techniques (calibrated on the modern sea bed) to yield estimates of seasonal surface-water temperatures and salinity. The first result is presented here. Considered as an anomaly pattern measured from today's base-line, the thermal response of the sea-surface 18,000 years ago is roughly the same both in magnitude and geographic pattern as a map of today's seasonal range. Changes in some mid-latitude sites reach and sometimes exceed 10°C. Except for upwelling areas, low latitude changes are on the order of 2°C, and in some subtropical areas show no change. Other features are: 1) the marked equatorward displacement of polar fronts in the N. Atlantic and Southern Ocean, but not in the N. Pacific; 2) the areal expansion of subpolar waters in all oceans; 3) the stable geometry of the subtropical gyres in all oceans; 4) the steepened thermal gradients across polar fronts, apparently marking the axis of ice-age westerlies in both hemispheres; 5) an increase in the extent of sea ice: at all seasons in the N. Atlantic, and especially during the austral summer in the Southern Ocean.

M5
Andrew McIntyre
Lamont-Doherty Geological Observatory of Columbia Univ., Palisades, N.Y. 10964 and Dept. of Earth and Environmental Sciences, Queens College, Flushing, N.Y. 11367
Sponsor: R. K. Matthews

Elements of Order in Ice-age History: A Markovian View. Evidence of order is found both in the chronology of climatic change and in the spatial structure of ice-age climate. A quasi-periodic glacial-interglacial cycle with a time constant of about 100,000 years is clearly stamped on records of the past 500,000 years. During the peak of the last ice-age the ocean circulated in expanded cyclonic and restricted anticyclonic gyres. One hypothesis is that the first-order response of the system is partly determined by the value of changing boundary conditions (the geographic pattern of incoming annual and seasonal radiation as fixed by the earth's orbital parameters) and partly by the state of the system itself (including the global ice-inventory). Major glaciations are associated with long intervals of high meridional-gradients of annual incoming radiation, amplified by seasonal effects on the N. Hemisphere snow line. They are conditioned globally by geostrophic expansion and contraction of oceanic gyres which, especially in the N. Atlantic, alter the pattern of poleward energy-transport. Superposed on this first-order pattern are small amplitude fluctuations of unknown origin, such as those of a minor cycle of about 2,500 years; and random fluctuations. In this view, climate is a non-stationary Markov process having considerable memory and exhibiting both deterministic and random elements.

M6
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Numerical Simulation of Ice-age Climate. Using the paleoclimatic boundary conditions assembled by CLIMAP, an experiment is in progress which aims to simulate numerically the global climate which accompanied the last ice age some 18,000 years ago. The first reconstruction will be for the Northern Hemisphere summer. The distributions of sea-surfaced temperature, ice extent and elevation, and surface albedo, together with a sea-level lowering of 85m, will be used with an improved version of the two-level atmospheric general circulation model. An integration of several month's length is envisaged in order to characterize the mean August values of the principal climatic elements, such as pressure, temperature, and rainfall. Verification is to be made against independent data on continental climate, chiefly pollen records.

M7
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Perspectives on Climatic Change. As clearly apparent from earlier presentations in this session, paleoclimatology is well on its way at last to achieving the status of a quantitative science. On the one hand, reconstructions of the chronology of Quaternary climate not only are capable of being expressed in physical terms readily interpretable by the atmospheric scientist but enjoy absolute dating controls sufficient to permit reliable correlations with datable environmental events, thereby facilitating the intelligent investigation of causal mechanisms of the ice ages. On the other hand, the realistic numerical simulation of past climates by means of general circulation modeling experiments is fast becoming a realizable goal, with many encouraging results already achieved and little reason to doubt that both climate theory and computer technology will suffice in the rather near future to pin down both the mechanism and the root cause (or causes) of the grand glacial-interglacial succession of the Quaternary. Against this auspicious background, the present state of our understanding of the ice-age problem, and that of the related problem of long-range climate prediction, will be briefly assessed.

M8
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